

|  |   |  |   |  |
|--|---|--|---|--|
| <b>REPORT DOCUMENTATION PAGE</b>   |   |  | <i>Form Approved</i><br><b>OMB No. 0704-0188</b>                    |  |
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503. |   |  |   |  |
| <b>1. AGENCY USE ONLY (Leave blank)</b>  |   | <b>2. REPORT DATE</b><br>26.Oct.98             | <b>3. REPORT TYPE AND DATES COVERED</b><br>MAJOR REPORT             |  |
| <b>4. TITLE AND SUBTITLE</b><br>IRIDIUM TTC GROUND STATION NUMBER & LOCATION OPTIMIZATION  |   |  | <b>5. FUNDING NUMBERS</b>   |  |
| <b>6. AUTHOR(S)</b><br>2D LT MASINO AARON J  |   |  |   |  |
| <b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b><br>UNIVERSITY OF COLORADO AT COLORADO SPRINGS  |   |  | <b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>                     |  |
| <b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b><br>THE DEPARTMENT OF THE AIR FORCE<br>AFIT/CIA, BLDG 125<br>2950 P STREET<br>WPAFB OH 45433   |   |  | <b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b><br><br>98-015 |  |
| <b>11. SUPPLEMENTARY NOTES</b>   |   |  |   |  |
| <b>12a. DISTRIBUTION AVAILABILITY STATEMENT</b><br>Unlimited distribution<br>In Accordance With AFI 35-205/AFIT Sup 1  |   |  | <b>12b. DISTRIBUTION CODE</b>                                       |  |
| <b>13. ABSTRACT (Maximum 200 words)</b><br><br><div style="text-align: center; font-size: 2em; font-weight: bold;">19981119 013</div><br><div style="text-align: center; font-weight: bold;">DOW QUALITY INSPECTED 4</div>   |   |  |   |  |
| <b>14. SUBJECT TERMS</b>   |   |  | <b>15. NUMBER OF PAGES</b>  |  |
|  |   |  | <b>16. PRICE CODE</b>   |  |
| <b>17. SECURITY CLASSIFICATION OF REPORT</b>   | <b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> | <b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> | <b>20. LIMITATION OF ABSTRACT</b>                                   |  |

# Iridium TTC Ground Station Number and Location Optimization

1 May 1998

Aaron J. Masino

ME Space Operations

“All rights reserved. No part of this report may be reproduced, in any form or by any means, without permission in writing from the author.”

## **Table of Contents**

| <b><u>Chapter</u></b>     | <b><u>Page</u></b> |
|---------------------------|--------------------|
| 1. Abstract               | ii                 |
| 2. Nomenclature           | iii                |
| 3. Background             | 1-4                |
| 4. Introduction           | 4-7                |
| 5. Orbital Analysis       | 7-10               |
| 6. Method                 | 10-14              |
| 7. Results                | 14-15              |
| 8. Limitations            | 15-17              |
| 9. Applications           | 17-18              |
| 10. Conclusion            | 18                 |
| 11. References            | 19                 |
| 12. Appendix 1            | 20-41              |
| 13. Appendix 2            | 42-43              |
| 14. Appendix 3 (C++ code) | 44-71              |
| 15. Appendix 4            | 72                 |
| 16. Appendix 5 (results)  | 73-79              |

## **Abstract**

The commercialization of space missions has led to the need for cost minimization in order to make these ventures commercially viable. In the past, commercial space systems have generally consisted of a single satellite in a geo-stationary orbit. Command and control of these systems required only a single ground station and cost was not an issue. However, with the crowding of the geo-stationary belt and the desire for truly global wireless communication, companies have now begun developing mission concepts using proliferated low Earth orbit (LEO) satellite systems. These systems cannot be commanded by a single ground station. Therefore, in order to minimize cost for the system, the minimum number of ground stations required for command and control operations must be determined. This paper develops a method for determining the minimal number of ground stations required to command and control Motorola's Iridium satellite constellation during the mission phase. The method relies on the use of the Iridium satellites' ability to communicate with other satellites in the system, that is the satellites' cross-link abilities. Using a computer model, the method will determine which satellite is currently in view of a given "candidate" ground station position. Then, based on delay time for ground station processing and satellite processing, the method will determine how many satellites the current ground station could command using satellite cross-links. It does this for every latitude and longitude position until it finds the position that can command the most satellites in the system. From there, the method determines the next ground station position in the same manner, until all the satellites have been commanded. Limitations of the given method as well as generalizations that can be made to the method in order to determine the minimal number of ground stations required for normal operations of any proliferated LEO satellite system are discussed.

## **Nomenclature**

- $D$  is the total time necessary for a ground station to command a given satellite
- $p$  is the amount of time that a ground station's request for information or a satellite's response to that request waits in the transmission queue
- $x$  is the command load processing time on the ground, that is the amount of time that it takes a ground station to generate a command load for a given satellite once it has received health and safety data on that satellite
- $y$  is the ground station processing time, that is the amount of time that it takes for a ground station to process a satellites health and safety information before it begins generating a command load
- $z$  is the satellite processing time, that is the amount of time it takes to process and package health and safety information before transmission, once it has acted on a request for information
- $\alpha$  is the number of cross-links that must be used in order for a ground station communicating with satellite A to communicate with satellite B
- $\beta$  is the number of cross-links that satellite B must use in order to reach a ground station which is communicating with satellite A
- $\epsilon$  the time at which for one satellite pass over a ground station the geometry of the problem changes, that is the satellites maintaining left and right cross-links change (explained below)

## **Background**

Motorola's Iridium project is a proliferated low Earth orbit (LEO) satellite system that is designed to provide global wireless communication needs such as voice, paging, data and facsimile transmissions.[1] The system works much like a cellular phone. The major difference between a cellular phone and an Iridium phone is that, unlike a cellular phone, an Iridium phone can be used anytime, anywhere in the world. Instead of relying strictly on cellular towers, an Iridium phone can, when a cellular tower is unavailable, access a satellite. Calls made from one location on the Earth are relayed via satellite cross-links to another part of the Earth. The system works on two levels. A user phone first attempts to access a local cellular tower. If a cellular tower is available, the user phone will operate using the cellular tower in the same manner as a cellular phone. If a cellular tower is unavailable, the user phone will access a satellite. The satellite will then route the call through a path from itself to a satellite that is over the location of the second user. The second user does not have to be using an Iridium phone. A satellite transmits calls to the ground where gateways relay calls from the satellite to standard telephone lines.[1]

The system consists of 66 satellites. The satellites are in 6 orbital planes with 11 operational satellites per plane. The satellites are in near circular orbits at an altitude of 780 kilometers with a period of 100 minutes 27 seconds.. The planes are inclined at 86.4 degrees for a near polar orbit.[2] This orbital configuration provides 100 percent coverage of the Earth's surface.

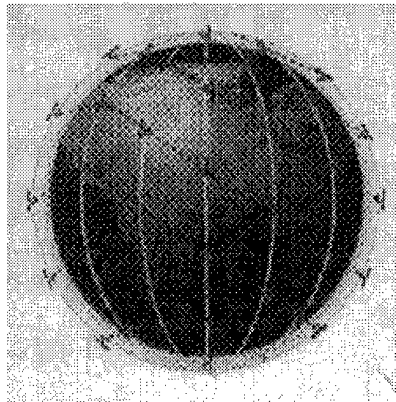


fig 1. Iridium orbital planes

The satellites themselves are equipped with an extensive communications package. Transmissions are made to the ground using 48 spot beams with a link margin of 16 dB for voice communications. [1] Each satellite is equipped with four additional antennas for cross-link purposes. Satellites are capable of directly communicating with four other satellites. Any given satellite can transmit information to and receive information from the satellite in front of and behind it in the same orbital plane and the satellites to its immediate right and left in the adjacent planes. However, as the satellites approach the poles, the cross-links to the satellites in the adjacent planes are lost. However, the links within the same plane are maintained.[3] The particular latitude of this cross-link outage will be discussed below.

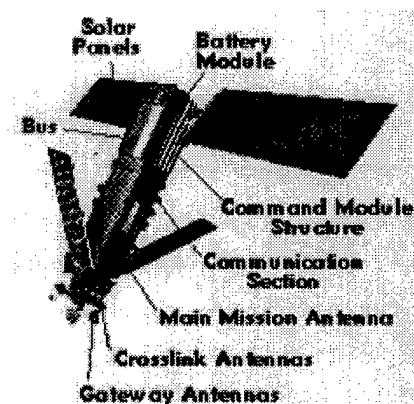


fig. 2 Iridium Satellite

Ground stations are needed to operate and maintain these satellites. Operating and maintaining a satellite involves several functions. The state of health of every satellite has to be

monitored. Health and safety data includes information on all the subsystems of the satellite, such as the communications, power and thermal systems. Depending on the complexity of the satellite, this data can grow quite large. For the Iridium system, the health and safety of each satellite is a relatively small amount of data. The only systems that are critical are power and the communications payload.[4] However, upon review of health and safety information, ground crews must handle anomaly resolution. If a satellite is operating outside of its normal parameter range, the satellite must be “safed” until the ground crew develops a command load that addresses the anomaly. These commands must then be uploaded to the satellite. Once the commands are uploaded, the satellite must be monitored further to ensure that the command load worked as planned. If the command load failed to resolve the problem, the whole process must be repeated. In a system of 66 satellites, resolving anomalies, which are sometimes frequent, could potentially become a major operations crisis. In a commercial system, the system availability must be extremely high, therefore, anomalies must be resolved quickly.

An even larger problem for Iridium operators will be maintaining the integrity of the constellation. Orbit management will be critical to the Iridium project. As the satellites tend to drift from their original positions, operators must, on a regular basis, conduct ranging on each satellite to determine orbital parameters and move the satellites into their proper orbital slots. Time keeping will also be crucial to the system. Because timing for the constellation is critical to a digital communications system, a master clock must be maintained at an operations center. This clock must then be used to constantly update each satellite clock. For a system in a LEO orbit, such as Iridium, the accuracy of the satellite clocks must be monitored frequently. Finally, there is the issue of network management. Because the satellites are moving so quickly, the pattern of cross-links used to route a transmission from one satellite to another is constantly

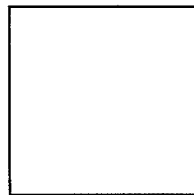


changing. Although the Iridium satellites each have on-board routing software to conduct this function, the integrity of the software must be monitored by the ground stations. Should there be a problem with this software on any satellite, that problem must be resolved almost immediately. If it is not, there will be lost transmissions on a regular basis which is not acceptable in a commercial system.

### **Introduction**

The goal of this study is to determine the minimal number of ground stations required to command and monitor health and safety information for the entire Iridium constellation within the time of a single satellite pass over each of the ground stations. Although this time limit is somewhat strict, it is realistic. These satellites must be working properly in order for the system to work. System failure leads to lost customers. For a system that has already cost over 6 billion dollars, a loss of customers is not an option.[2]

The number of ground stations required to meet this standard will be based on different values of total time to command a satellite,  $D$ , where:



$$D = (x + y + z) + (\alpha + \beta + 2)p \quad (1)$$

where  $x=2$  seconds, command load processing time  
 $y=5$  seconds, ground station processing time  
 $z=1$  second, satellite processing time  
 $\alpha$  and  $\beta$  are defined in the nomenclature

Although the actual values of these parameters are currently unavailable from Motorola, the estimated values are realistic because the satellites are relatively simple and the command

loads are of a standard form.[4] If there is an anomaly, a satellite will automatically be sent a safe command. The ground crew will attempt to develop a solution to the anomaly. Once the solution command load has been developed, it will be sent to the afflicted satellite using the satellite that has currently moved into view. This allows a ground crew to command as many satellites as is possible in one satellite pass without spending the entire pass time attempting to resolve an anomaly.

Because  $x$ ,  $y$  and  $z$  are constant the only varying factor in equation 1 is the amount of time that a ground station request or a satellites reply to a request waits in the satellite's transmission queue,  $p$ . When a ground station sends a request for information, that request is placed into the same queue as customer transmissions. When a satellite collects its health and safety information and packages a response to the ground station, that response is also placed into the transmission queue. This transmission queue uses a priority system. Customer transmissions have a higher priority than health and safety requests and replies.[3] Therefore, the higher the amount of customer activity the longer a request or reply will wait for transmission on-board any given satellite. The value of  $p$  will therefore be set at different values so that the number of ground stations required will be based on a given value of  $p$ . The value of  $p$  will be assumed to be a constant for all satellites for any given ground station number determination. This is a limitation, however, because a more accurate model would change  $p$  based on each satellite's current location. This is true because a satellite over North America for example, is most probably going to have a higher value of  $p$  than one currently over the Pacific ocean due to an obviously higher number of users in the region of North America than in the Pacific ocean. However, expected data loads, and resulting delay times for health and safety requests/replies, by region are unavailable from Motorola, thus the given development of  $p$  will be used.

The approach of this paper will be to first conduct an orbital analysis. This is necessary to determine a mean time in view. It is also necessary so that the arrangement, or geometry, of the satellite constellation during a ground station pass can be understood. As discussed below, an understanding of the geometry of the problem will greatly ease the resulting algorithm to determine the required number of ground stations.

Once the orbital analysis is done, the next step is to determine the number of ground stations required for a given value of  $p$ . This will be discussed in detail below, but the general method is to cycle through all latitude and longitude combinations for the first ground station. Using the mean time in view and the current constellation geometry determine which satellite is closest to that latitude longitude combination. If it is assumed that no ground stations will be placed above 65 North latitude or below 65 degrees South latitude, the worst case will be that only one satellite will be in view of the ground station but there will always be at least one. That is, after all, the point of the Iridium project. The requirement that ground stations not be above 65 N or below 65 S forces the worst case of having only one satellite in view. Above these latitudes a ground station would always have access to more than one satellite. However the only land below 65 S latitude is Antarctica and the only land above 65 N latitude are the extreme northern regions of Canada, Greenland and Russia. All of these areas are assumed to be out of use due to practical considerations of weather and expense. Using this satellite and the current delay time, determine the number of satellites that this particular latitude longitude combination could command and control. Doing this for each latitude and longitude combination, find the one that can command the most satellites. Continue doing this for successive ground stations until all satellites have been commanded. This, however, may result in an optimal ground station

being placed in a latitude longitude combination that is located over water or in a politically unstable region. Therefore the optimal ground stations may have to be altered.

The software that has been developed is capable of first giving the optimal ground station locations. Then, once the user has modified the locations to correct for water and political considerations, the software is capable of determining whether or not these locations will be able to command all of the satellites. If not, at least one more ground station will be required to command and control the entire constellation. A limitation of the software is that it assumes that the orbital analysis has been conducted previously. Thus when used, the software must be given the mean time in view and the satellite constellation geometry, as is discussed below.

### **Orbital Analysis**

In order to determine a mean time in view and to develop an understanding of the constellation geometry, an extensive orbital analysis was conducted using Satellite Tool Kit from Analytical Graphics, Inc. The first required piece of information was a mean time in view for a satellite pass over a ground station. This was done by placing a satellite into an Iridium orbit. The satellite was then fixed with a communications sensor. The sensor was given an outer half angle of 70 degrees. Thus the sensor did not use a spot beam but a semi-omni directional type antenna. Then a ground station facility was placed in three positions, one at 55 degrees south latitude, one at 0 degrees latitude and one at 55 degrees north latitude. A communications sensor was located at each ground station. The minimum elevation angle was set at three different angles, 10, 15 and 20 degrees. The chains tool within Satellite Tool Kit was then used to create a link between the satellite antenna to each of the ground station antennas at each elevation angle. Finally, the reports tool was used to create a report on the access times between the satellite antenna and the ground station antenna for each ground station at each elevation angle. The

reports are listed in appendix 1 and are for a period of 10 days. The nine different mean duration times were then averaged to arrive at a mean time in view of:

$$\frac{5155.113}{9} = 572.790\bar{3} \text{ sec} = 9.55 \text{ min (2)}$$

where the 9 mean times in view are:

| Latitude | Elevation (deg) | Mean Time In View(seconds) |
|----------|-----------------|----------------------------|
| 0        | 10              | 597.085                    |
| 0        | 15              | 554.248                    |
| 0        | 20              | 521.518                    |
| 55 North | 10              | 626.954                    |
| 55 North | 15              | 600.532                    |
| 55 North | 20              | 579.44                     |
| 55 South | 10              | 609.899                    |
| 55 South | 15              | 557.981                    |
| 55 South | 20              | 507.459                    |

The next step was to determine the latitude at which the satellite's left and right cross-links stop working. The exact value is Motorola proprietary information and thus had to be determined using Satellite Tool Kit. This was done by forming an Iridium constellation and placing a sensor on two satellites in adjacent planes. The sensors were set to fixed targeting so that they were intended to communicate with each other only. Next, the chains tool was again used to connect the two satellite antennas. Finally, a report was generated to determine the contact period of the satellite starting at 0 degrees latitude and ending at 90 degrees latitude. The length of the contact period was 1211.274 seconds. The report is given in appendix 2. Assuming a spherical Earth and knowing the period of an Iridium satellite, it is possible to determine a ratio of degrees latitude covered per second as:

$$\frac{360}{6027.14} = .059729822 \frac{\text{deg}}{\text{sec}}$$

Now, knowing the length of the contact period and the fact that the contact period began at 0 latitude and that this period was continuous, it is possible to determine the latitude at which the cross-link was lost as:

$$\begin{aligned} lat &= 90 - (1506.785 - 1211.274).059729822 \\ lat &= 72.349 \text{ deg} \end{aligned} \quad (3)$$

where 1506.785 is  $\frac{1}{4}$  of the satellites period in seconds, that is the time required for the satellite to travel from 0 degrees latitude to 90 degrees latitude.

The final result needed from the orbital analysis was a development of the constellation geometry. The constellation is remarkably well behaved. At any one time there are always 3 satellites in each plane that are without left and right cross-links. The geometry is constant in that there are always two satellites in each plane that are either above 72 N latitude or below 72 degrees S latitude and one satellite at the opposite pole. The remaining 8 satellites in each plane are evenly spaced between 72 S and 72 N latitude. So that for any given longitude and latitude combinations below 65 N or above 65 S a ground station will have access to the same satellite in one pass for the stated mean time in view and for that pass there will be exactly 8 satellites in each plane that can maintain cross-links. However the geometry does change once during this pass. From the start of the satellite pass over a ground station the same 8 satellites in each orbital plane maintain cross-links until a time  $\epsilon$ . At  $\epsilon$ , the most northerly satellites moving in ascending motion that had maintained left and right cross-links, lose them. At the same time the most southerly satellites moving in descending motion lose their left and right cross-links. However at this same time,  $\epsilon$ , new satellites descend below 72 N latitude and ascend above 72 S latitude so that there are still 8 satellites maintaining left and right cross-links. If a satellite pass

is said to begin at time zero, then  $\epsilon$  occurs at

$$\epsilon = 3 \text{ min } 27 \text{ sec}$$

into the satellite pass.

The importance of this geometry stability will become evident below in the discussion of the algorithm used to solve for the minimal number of ground stations required.

### **Method**

Once the geometry has been determined, the method for determining the minimum number of ground stations using computer software follows. The software uses the fact that for any satellite pass over a ground station the geometry will be the same. As stated, the satellite will access one of the four satellites in a plane that maintains left and right cross-links. There will always be 8 satellites per plane that are capable of left and right cross-links. Further, there will be only one change in geometry in the pass, at time  $\epsilon$ , as stated. The fact that the geometry does not change allows this problem to be treated statically. Using Satellite Tool Kit, the initial latitude and longitude of the sub-satellite positions can be determined. The next step is to number the satellites in each plane 1 through 11. Satellite Tool Kit will do this automatically. The final step is to determine the numbered satellites that lose left and right cross-links for the pre-epsilon time and the post-epsilon time, that is which satellites are above 72° N and below 72° S. The satellites will be the same for each plane. For example, if satellite 1 in plane 1 has lost left and right cross-links, then satellite 1 in every other plane will have lost left and right cross-links. Appendix 4 has a picture of the ground track.

From Appendix 4, it is seen that for the Iridium setup, the satellites that have lost left and right cross-links before  $\epsilon$  are satellites 3, 8, and 9 in each plane. The next step is to determine

which satellites have lost left and right cross-links after  $\epsilon$ . For this case, satellites 2, 3 and 8 in each plane have lost their left and right cross-links.

At this point the computer algorithm is ready to begin. The program will first query the user for information on the cross-links. It will ask for the number of the satellites that have lost cross-links before and after  $\epsilon$  and for the transitional case. So for this case the satellites that have lost left and right cross-links before  $\epsilon$  are entered as 3, 8 and 9. The satellites that have lost left and right cross-links after  $\epsilon$  will be entered as 2, 3 and 8. Finally, the transitional case, the satellite numbers will be entered as 2, 3, 8 and 9. The transitional case will be explained below.

The cross-link information is used by the software to create a computer graph. A graph is defined as a set of vertices and arcs. An arc between vertex  $a$  and vertex  $b$  means that it is possible to travel directly from  $a$  to  $b$  and from  $b$  to  $a$ . [5] For this software, the vertices are the satellites and an arc from satellite  $A$  to  $B$  represents a direct cross-link between satellites  $A$  and  $B$ . The graph will be represented by an adjacency matrix. An adjacency matrix is an  $n \times n$  matrix. In this case, the rows and columns of the matrix are each of the satellite labels. The satellites are labeled 0 to 65. The reason for beginning at 0 and not 1 is that C++ sets array (i.e. matrix) origins at (0,0). Entries in the matrix are Boolean values, represented by 0 and 1. A one value in the position  $i,j$  in the matrix indicates that there is a cross-link between satellites  $i$  and  $j$ . By convention, a vertex is always considered to be connected to itself, thus all positions  $i,i$  will be given a value of 1. [5] Using this method and the cross-link information entered by the user, the software develops three adjacency matrices. The first represents the graph cross-link information before  $\epsilon$ . The second represents the graph cross-link information after  $\epsilon$ . The third is used for the special case of when satellite  $A$  is attempting to send a message to satellite  $B$  using cross-links and the time  $\epsilon$  passes before the message arrives at  $B$  but has already left  $A$ . That is,



when satellite A originally transmits the message to some intermediate satellite, it does so before  $\epsilon$ , so that the pre-epsilon geometry is correct. However while the message for satellite B is at an intermediate satellite,  $\epsilon$  passes. At this point, the post-epsilon geometry takes over. However determining the exact satellite location of this geometry change makes the problem too dynamical. It is more consistent to assume an intermediate geometry in which four satellites in each plane have lost cross-links, those being the satellites 2, 3, 8 and 9 for this case. Because it can be determined a priori if a transmission will be subject to this condition, the third adjacency matrix can be used for this case.

Once the program has formed these adjacency matrices it must next read the satellite latitude and longitude information. These are the values determined by Satellite Tool Kit and are read in from a file. The program will ask the user for the filenames that contain the latitude and longitude information. All that is required of the user is to enter the names.

The software is now ready to compute the number of ground stations required. It does so by first choosing a candidate latitude and longitude position for a ground station. The software considers positions at 5 degree increments, although this could easily be modified to different increments by change the step size of the loop counters.

It next finds the satellite that is closest to the current ground station location. It does this by comparing the ground station longitude and latitude to each satellite longitude and latitude. The satellite with the smallest absolute difference is chosen as the root satellite, meaning that this satellite will act as the one in view of these coordinates for the satellite pass.

The software next finds the shortest path between the root satellite and every other satellite. It does this using Dijkstra's Algorithm, as described by Budd, which is a single source shortest path algorithm.[5] Dijkstra's Algorithm is used to determine the number of cross-links,

$\alpha$ , required to reach a given satellite from the root satellite. With this information, the request delay time is determined as:

$$request = (\alpha + 1)p + z \quad (4)$$

The adjacency matrix used is determined by  $\alpha p$ . If this value is less than  $\epsilon$ , then the pre-epsilon matrix is used, otherwise the special case matrix is used. Dijkstra's Algorithm is then used to determine the shortest path from a given satellite to the root satellite. It will return the number of cross-links,  $\beta$ , required to reach the root satellite from the current satellite. If

$$request + x + y \leq \frac{\epsilon}{2}$$

then the pre-epsilon matrix is used. If

$$\frac{\epsilon}{2} < request + x + y < \epsilon$$

the special case matrix is used. Finally if

$$request \geq \epsilon$$

the post-epsilon matrix is used. The respond delay time is computed by

$$respond = (\beta + 1)p \quad (5)$$

The total delay time is composed of the delay time for a ground station request to reach the satellite and the delay time for the satellite response to reach the ground station. So total delay time is given by:

$$D = request + response + x + y \quad (6)$$

It is assumed that if the ground station transmits the command load before the satellite pass is over than that satellite has been commanded. That means that the root satellite may move out of

view of the ground station before the command load has reached the destination satellite as long as the ground station transmits the command load to the root satellite while it is still in view. If

$$D \leq \text{mean\_time\_in\_view}$$

then the satellite is tagged as having been commanded by the current ground station. This is done for each satellite at each ground station location. The ground station that commands the most satellites is then chosen as the first ground stations. The whole process is now repeated to find the second satellite until all satellites have been commanded by the set of ground stations. Note that after each ground station is determined the satellites that it commands are permanently tagged as having been commanded. This is done so that when the successive ground station is chosen it only considers satellites that haven't been commanded as contributing to the new ground stations commanding ability. However, when attempting to access the remaining satellites, the new ground station still has access to all cross-links because it still uses the original three adjacency matrices.

Once the final set of ground stations has been determined the program returns the number of ground stations required as well as their latitude and longitude positions. The code listing is given in Appendix 3.

## **Results**

The basic result is that as  $p$  increases the required number of ground stations also increases (Appendix 5). The most important values are those for  $p$  between 1 and 56 seconds. If  $p$  is 30 seconds or less the entire constellation can be commanded with one ground station. This ground station can be located at any latitude and longitude. By appendix 5 the optimal value of the ground station location is 65 N latitude and 180 longitude. This determination, however, is due to the way that the computer algorithm selects a ground station. The first latitude and

longitude combination that it considers is 65 N latitude and 180 longitude. Because this ground station succeeds in commanding all of the ground stations the algorithm does not consider others. However using the subroutine, test\_gs, the user can test certain ground station locations to determine if those locations will command all of the satellites for the given value of p. Using this subroutine it has been determined that for p less than or equal to 30 seconds the single ground station can be located at any latitude and longitude combination. At p equal to 35 seconds, the required number of ground stations increases to 2. Two ground stations are required for p between 35 and 56 seconds. The optimal locations for each value of p in this range is given in Appendix 5. Once p increases beyond 56 seconds 4 or more ground stations are required to command the constellation as listed in Appendix 5. The subroutine test\_gs can again be used on these values to determine whether or not adjustments to these locations will still command the entire constellation. For example, if p is set to 45 seconds then two ground stations in the United States at 40 latitude and -80 and -120 longitude can command the entire constellation. However for p greater than or equal to 50 seconds no two ground stations on land can command the entire constellation. Therefore the satellite capacity would have to be designed to be less than 46 seconds to have to land based ground stations. Note also from Appendix 5 that at no value of p are 3 ground stations required. At 57 seconds, the required number of ground stations is 4. The Iridium system currently calls for 3 ground stations. However, as it has been shown, only two are necessary. This reduction will greatly reduce costs because one less ground station is required and therefore fewer operators are required.

### **Limitations**

There are certain limitations to this approach. The first and most important is the restriction that the number of ground stations determined must be capable of commanding all

satellites for a single mean pass time. This restriction forces the determined number of ground stations to have the capability to constantly command and control all of the satellites. This is true because as the current root satellite at each ground station move out of view a new root satellite will be moving into view. Other approaches might restrict the determined number of ground stations as having the ability to only command all of the satellites once every orbital period, once every 8 hours, once every day, etc. Such an approach would require long term knowledge of the constellation geometry. Each satellite that comes into view of a ground station during the given period would have to be determined for each ground station location. For each of those satellites the in-view period would have to be determined. Finally using each in view period, the particular satellites that could be commanded from that ground station location would have to be determined. This would have to be done for each ground station candidate location. The process is similar to that given in this paper. However, the need for long term knowledge of the orbit in order to determine each satellite that will come into view of each ground station location makes the problem extremely dynamical. Furthermore, as stated above, because this is a commercial venture, that requires that all satellites be working properly, if they are monitored only periodically problems may arise. For example, if every satellite is commanded only once every 4 hours, a given satellite suffering from an anomaly could be down more than 4 hours. If only a few satellites are down for a few hours at a time, system performance will degrade dramatically.

The other limitation is the case for which a transmission is made from satellite A to satellite B using the special case adjacency matrix. This case has assumed that for the entire path from A to B that there are four satellites in each plane that have lost left and right cross-links. The true case, however, is that for the path there will only be 3 satellites in each plane that have lost left and right cross-links. At some point along that path the satellites that lose these cross-

links changes. This approach does not attempt to determine where in the path that this change occurs, but rather assumes that for the entire path the cross-links lost in the pre-epsilon and post-epsilon geometry have been lost for this particular case. Another method could determine the location along the path that the geometry changes and compute the remaining path from the intermediate satellite to the destination satellite using the post-epsilon geometry.

### **Applications**

The given method has two applications. It can be used to determine the minimal number of ground stations required for any proliferated LEO constellation. Certain modifications would, however, have to be made to the developed software. An orbital analysis would be required of the given constellation to determine the parameters required as discussed above. The software would have to be modified to account for an increase or decrease in the number of orbital planes, number of satellites per plane and the total number of satellites in the constellation. Secondly, the software would have to be modified to fit the cross-link capability of the given system. For example if the new system had more or less than 4 cross-links per satellite this must be corrected in the software. The software would also have to be modified to account for which satellites in each plane may have lost certain cross-link capabilities. The last modification would have to account for more than one geometry change in a satellite pass over the ground station. For each time, or  $\epsilon$ , at which the geometry changes a new adjacency matrix must be determined. This new matrix would then be used as described above to determine the path from satellite A to satellite B.

Another application of this method is a by product of the shortest path algorithm. With the use of knowledge of the constellation orbit and timers, an adjacency matrix for each satellite at each time period could be determined. Once done this could be used at the satellites routing software. For a satellite attempting to relay a call from one location on Earth to another, it could

use the current adjacency matrix to determine the shortest path from its location to the destination location. This combined with a knowledge of which satellites are currently in safe-mode and are therefore unavailable to the path could provide efficient routing software. Currently each Iridium satellite has on-board routing software, but the nature of this software is Motorola proprietary information and is therefore unavailable.[3]

### **Conclusion**

Commercialization of space operations requires efficient operations at low costs. This requirement forces commercial developers to determine the minimal number of ground stations required to command and control their space assets. This paper has discussed a method for determining the minimal number of ground station required to command and control Motorola's Iridium constellation. It also discusses how to apply this method to other cross-linked LEO constellations as well as certain limitations of this method.

### References

1. <http://alishaw.sscf.ucsb.edu/~sung/comm115/Iridium.html>, "Iridium (Motorola)".
2. [http://www.mot.com/GSS/SSTG/SATCOM/FAQ\\_A.html](http://www.mot.com/GSS/SSTG/SATCOM/FAQ_A.html), "System Information".
3. Howe, Jim. Senior Spacecraft Analyst, Allied Signal Technical Services. E-mail correspondence, 3 Mar 1998.
4. Mullikin, Thomas L. Sole Proprietor, Aerospace Consulting. E-mail correspondence, 25 Feb 1998.
5. Budd, Timothy A. Classic Data Structures in C++. New York: Addison-Wesley Publishing Co., 1994.



## Appendix 1

Latitude 0 deg Elevation 15

11 Apr 1998 14:04:33

Chain-sat\_ground\_lat0: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| 1      | 1 Jan 1997 04:05:06.94 | 1 Jan 1997 04:14:07.63 | 540.695        |
| 2      | 1 Jan 1997 05:44:23.70 | 1 Jan 1997 05:55:38.02 | 674.322        |
| 3      | 1 Jan 1997 16:40:26.69 | 1 Jan 1997 16:51:45.70 | 679.011        |
| 4      | 1 Jan 1997 18:22:04.69 | 1 Jan 1997 18:30:53.53 | 528.831        |
| 5      | 2 Jan 1997 03:34:01.61 | 2 Jan 1997 03:38:35.05 | 273.434        |
| 6      | 2 Jan 1997 05:10:22.39 | 2 Jan 1997 05:22:16.95 | 714.562        |
| 7      | 2 Jan 1997 06:56:24.43 | 2 Jan 1997 06:58:45.64 | 141.215        |
| 8      | 2 Jan 1997 16:07:37.61 | 2 Jan 1997 16:17:07.87 | 570.264        |
| 9      | 2 Jan 1997 17:47:23.42 | 2 Jan 1997 17:58:23.78 | 660.357        |
| 10     | 3 Jan 1997 04:36:53.86 | 3 Jan 1997 04:48:25.58 | 691.726        |
| 11     | 3 Jan 1997 06:19:09.94 | 3 Jan 1997 06:27:19.72 | 489.779        |
| 12     | 3 Jan 1997 15:35:37.23 | 3 Jan 1997 15:41:19.79 | 342.566        |
| 13     | 3 Jan 1997 17:13:18.27 | 3 Jan 1997 17:25:10.48 | 712.205        |
| 14     | 4 Jan 1997 04:04:02.38 | 4 Jan 1997 04:14:01.61 | 599.230        |
| 15     | 4 Jan 1997 05:44:08.22 | 4 Jan 1997 05:54:49.32 | 641.097        |
| 16     | 4 Jan 1997 16:39:43.63 | 4 Jan 1997 16:51:23.86 | 700.221        |
| 17     | 4 Jan 1997 18:22:07.44 | 4 Jan 1997 18:29:35.86 | 448.415        |
| 18     | 5 Jan 1997 03:32:11.65 | 5 Jan 1997 03:38:53.39 | 401.741        |
| 19     | 5 Jan 1997 05:09:53.46 | 5 Jan 1997 05:21:40.40 | 706.937        |
| 20     | 5 Jan 1997 16:06:40.76 | 5 Jan 1997 16:17:02.26 | 621.505        |
| 21     | 5 Jan 1997 17:47:08.72 | 5 Jan 1997 17:57:30.44 | 621.724        |
| 22     | 6 Jan 1997 04:36:12.61 | 6 Jan 1997 04:48:00.42 | 707.814        |
| 23     | 6 Jan 1997 06:19:29.10 | 6 Jan 1997 06:26:06.34 | 397.244        |
| 24     | 6 Jan 1997 15:34:18.95 | 6 Jan 1997 15:41:48.52 | 449.574        |
| 25     | 6 Jan 1997 17:12:51.03 | 6 Jan 1997 17:24:31.50 | 700.465        |
| 26     | 7 Jan 1997 04:03:05.85 | 7 Jan 1997 04:13:49.49 | 643.639        |
| 27     | 7 Jan 1997 05:43:59.12 | 7 Jan 1997 05:53:55.24 | 596.119        |
| 28     | 7 Jan 1997 16:39:05.05 | 7 Jan 1997 16:50:57.13 | 712.085        |
| 29     | 7 Jan 1997 18:22:19.97 | 7 Jan 1997 18:27:59.94 | 339.967        |
| 30     | 8 Jan 1997 03:30:46.65 | 8 Jan 1997 03:39:00.39 | 493.743        |
| 31     | 8 Jan 1997 05:09:29.28 | 8 Jan 1997 05:20:59.48 | 690.199        |
| 32     | 8 Jan 1997 16:05:49.60 | 8 Jan 1997 16:16:49.64 | 660.040        |
| 33     | 8 Jan 1997 17:46:59.70 | 8 Jan 1997 17:56:29.91 | 570.208        |
| 34     | 9 Jan 1997 03:00:38.50 | 9 Jan 1997 03:03:07.40 | 148.901        |
| 35     | 9 Jan 1997 04:35:36.12 | 9 Jan 1997 04:47:30.90 | 714.777        |
| 36     | 9 Jan 1997 06:20:13.50 | 9 Jan 1997 06:24:41.53 | 268.023        |
| 37     | 9 Jan 1997 15:33:10.36 | 9 Jan 1997 15:41:59.56 | 529.197        |
| 38     | 9 Jan 1997 17:12:28.26 | 9 Jan 1997 17:23:47.58 | 679.326        |

# Global Statistics

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| Min Duration   | 7  | 2 Jan 1997 06:56:24.43 | 2 Jan 1997 06:58:45.64 | 141.215 |
| Max Duration   | 35 | 9 Jan 1997 04:35:36.12 | 9 Jan 1997 04:47:30.90 | 714.777 |
| Mean Duration  |    |                        | 554.241                |         |
| Total Duration |    |                        | 21061.156              |         |

Latitude 0 degrees Elevation 10 degrees

11 Apr 1998 14:08:17

Chain-sat\_ground\_lat0: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| 1      | 1 Jan 1997 04:05:06.94 | 1 Jan 1997 04:14:51.54 | 584.607        |
| 2      | 1 Jan 1997 05:44:23.70 | 1 Jan 1997 05:56:27.98 | 724.276        |
| 3      | 1 Jan 1997 16:39:36.58 | 1 Jan 1997 16:51:45.70 | 729.125        |
| 4      | 1 Jan 1997 18:21:21.40 | 1 Jan 1997 18:30:53.53 | 572.121        |
| 5      | 2 Jan 1997 03:34:01.61 | 2 Jan 1997 03:38:59.48 | 297.873        |
| 6      | 2 Jan 1997 05:10:22.39 | 2 Jan 1997 05:23:08.15 | 765.763        |
| 7      | 2 Jan 1997 06:56:24.43 | 2 Jan 1997 06:58:56.16 | 151.729        |
| 8      | 2 Jan 1997 16:06:51.93 | 2 Jan 1997 16:17:07.87 | 615.945        |
| 9      | 2 Jan 1997 17:46:34.21 | 2 Jan 1997 17:58:23.78 | 709.570        |
| 10     | 3 Jan 1997 04:36:53.86 | 3 Jan 1997 04:49:15.94 | 742.082        |
| 11     | 3 Jan 1997 06:19:09.94 | 3 Jan 1997 06:28:01.10 | 531.157        |
| 12     | 3 Jan 1997 15:35:06.39 | 3 Jan 1997 15:41:19.79 | 373.405        |
| 13     | 3 Jan 1997 17:12:27.19 | 3 Jan 1997 17:25:10.48 | 763.284        |
| 14     | 4 Jan 1997 04:04:02.38 | 4 Jan 1997 04:14:48.33 | 645.943        |
| 15     | 4 Jan 1997 05:44:08.22 | 4 Jan 1997 05:55:38.06 | 689.836        |
| 16     | 4 Jan 1997 16:38:52.84 | 4 Jan 1997 16:51:23.86 | 751.020        |
| 17     | 4 Jan 1997 18:21:28.90 | 4 Jan 1997 18:29:35.86 | 486.956        |
| 18     | 5 Jan 1997 03:32:11.65 | 5 Jan 1997 03:39:28.71 | 437.057        |
| 19     | 5 Jan 1997 05:09:53.46 | 5 Jan 1997 05:22:31.40 | 757.936        |
| 20     | 5 Jan 1997 16:05:52.80 | 5 Jan 1997 16:17:02.26 | 669.463        |
| 21     | 5 Jan 1997 17:46:21.04 | 5 Jan 1997 17:57:30.44 | 669.403        |
| 22     | 6 Jan 1997 04:36:12.61 | 6 Jan 1997 04:48:51.34 | 758.735        |
| 23     | 6 Jan 1997 06:19:29.10 | 6 Jan 1997 06:26:41.54 | 432.437        |
| 24     | 6 Jan 1997 15:33:40.08 | 6 Jan 1997 15:41:48.52 | 488.438        |
| 25     | 6 Jan 1997 17:12:00.37 | 6 Jan 1997 17:24:31.50 | 751.128        |
| 26     | 7 Jan 1997 04:03:05.85 | 7 Jan 1997 04:14:38.06 | 692.207        |
| 27     | 7 Jan 1997 05:43:59.12 | 7 Jan 1997 05:54:42.11 | 642.991        |
| 28     | 7 Jan 1997 16:38:13.90 | 7 Jan 1997 16:50:57.13 | 763.227        |
| 29     | 7 Jan 1997 18:21:49.51 | 7 Jan 1997 18:27:59.94 | 370.426        |
| 30     | 8 Jan 1997 03:30:46.65 | 8 Jan 1997 03:39:41.73 | 535.079        |
| 31     | 8 Jan 1997 05:09:29.28 | 8 Jan 1997 05:21:49.96 | 740.683        |
| 32     | 8 Jan 1997 16:05:00.15 | 8 Jan 1997 16:16:49.64 | 709.489        |
| 33     | 8 Jan 1997 17:46:14.33 | 8 Jan 1997 17:56:29.91 | 615.585        |
| 34     | 9 Jan 1997 03:00:38.50 | 9 Jan 1997 03:03:18.73 | 160.237        |
| 35     | 9 Jan 1997 04:35:36.12 | 9 Jan 1997 04:48:22.08 | 765.958        |
| 36     | 9 Jan 1997 06:20:13.50 | 9 Jan 1997 06:25:05.54 | 292.036        |
| 37     | 9 Jan 1997 15:32:26.76 | 9 Jan 1997 15:41:59.56 | 572.800        |
| 38     | 9 Jan 1997 17:11:38.34 | 9 Jan 1997 17:23:47.58 | 729.239        |

# Global Statistics

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| Min Duration   | 7  | 2 Jan 1997 06:56:24.43 | 2 Jan 1997 06:58:56.16 | 151.729 |
| Max Duration   | 35 | 9 Jan 1997 04:35:36.12 | 9 Jan 1997 04:48:22.08 | 765.958 |
| Mean Duration  |    |                        | 597.085                |         |
| Total Duration |    |                        | 22689.243              |         |

Latitude 0 degrees Elevation 20 degrees

11 Apr 1998 14:10:25

Chain-sat\_ground\_lat0: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| 1      | 1 Jan 1997 04:05:06.94 | 1 Jan 1997 04:13:34.73 | 507.792        |
| 2      | 1 Jan 1997 05:44:23.70 | 1 Jan 1997 05:54:58.32 | 634.618        |
| 3      | 1 Jan 1997 16:41:06.60 | 1 Jan 1997 16:51:45.70 | 639.105        |
| 4      | 1 Jan 1997 18:22:36.94 | 1 Jan 1997 18:30:53.53 | 496.591        |
| 5      | 2 Jan 1997 03:34:01.61 | 2 Jan 1997 03:38:19.73 | 258.119        |
| 6      | 2 Jan 1997 05:10:22.39 | 2 Jan 1997 05:21:35.61 | 673.221        |
| 7      | 2 Jan 1997 06:56:24.43 | 2 Jan 1997 06:58:39.81 | 135.376        |
| 8      | 2 Jan 1997 16:08:12.30 | 2 Jan 1997 16:17:07.87 | 535.572        |
| 9      | 2 Jan 1997 17:48:02.35 | 2 Jan 1997 17:58:23.78 | 621.426        |
| 10     | 3 Jan 1997 04:36:53.86 | 3 Jan 1997 04:47:45.26 | 651.400        |
| 11     | 3 Jan 1997 06:19:09.94 | 3 Jan 1997 06:26:49.58 | 459.637        |
| 12     | 3 Jan 1997 15:35:57.65 | 3 Jan 1997 15:41:19.79 | 322.147        |
| 13     | 3 Jan 1997 17:13:59.48 | 3 Jan 1997 17:25:10.48 | 670.991        |
| 14     | 4 Jan 1997 04:04:02.38 | 4 Jan 1997 04:13:25.61 | 563.230        |
| 15     | 4 Jan 1997 05:44:08.22 | 4 Jan 1997 05:54:11.10 | 602.884        |
| 16     | 4 Jan 1997 16:40:24.42 | 4 Jan 1997 16:51:23.86 | 659.433        |
| 17     | 4 Jan 1997 18:22:34.87 | 4 Jan 1997 18:29:35.86 | 420.983        |
| 18     | 5 Jan 1997 03:32:11.65 | 5 Jan 1997 03:38:29.00 | 377.344        |
| 19     | 5 Jan 1997 05:09:53.46 | 5 Jan 1997 05:20:59.35 | 665.882        |
| 20     | 5 Jan 1997 16:07:18.04 | 5 Jan 1997 16:17:02.26 | 584.221        |
| 21     | 5 Jan 1997 17:47:45.83 | 5 Jan 1997 17:57:30.44 | 584.611        |
| 22     | 6 Jan 1997 04:36:12.61 | 6 Jan 1997 04:47:19.40 | 666.792        |
| 23     | 6 Jan 1997 06:19:29.10 | 6 Jan 1997 06:25:42.12 | 373.022        |
| 24     | 6 Jan 1997 15:34:46.60 | 6 Jan 1997 15:41:48.52 | 421.917        |
| 25     | 6 Jan 1997 17:13:31.74 | 6 Jan 1997 17:24:31.50 | 659.761        |
| 26     | 7 Jan 1997 04:03:05.85 | 7 Jan 1997 04:13:11.33 | 605.480        |
| 27     | 7 Jan 1997 05:43:59.12 | 7 Jan 1997 05:53:19.21 | 560.089        |
| 28     | 7 Jan 1997 16:39:46.30 | 7 Jan 1997 16:50:57.13 | 670.833        |
| 29     | 7 Jan 1997 18:22:40.11 | 7 Jan 1997 18:27:59.94 | 319.830        |
| 30     | 8 Jan 1997 03:30:46.65 | 8 Jan 1997 03:38:30.18 | 463.533        |
| 31     | 8 Jan 1997 05:09:29.28 | 8 Jan 1997 05:20:19.10 | 649.821        |
| 32     | 8 Jan 1997 16:06:28.68 | 8 Jan 1997 16:16:49.64 | 620.965        |
| 33     | 8 Jan 1997 17:47:34.20 | 8 Jan 1997 17:56:29.91 | 535.707        |
| 34     | 9 Jan 1997 03:00:38.50 | 9 Jan 1997 03:03:01.06 | 142.562        |
| 35     | 9 Jan 1997 04:35:36.12 | 9 Jan 1997 04:46:49.56 | 673.445        |
| 36     | 9 Jan 1997 06:20:13.50 | 9 Jan 1997 06:24:26.55 | 253.046        |
| 37     | 9 Jan 1997 15:33:42.80 | 9 Jan 1997 15:41:59.56 | 496.755        |
| 38     | 9 Jan 1997 17:13:08.04 | 9 Jan 1997 17:23:47.58 | 639.543        |

# Global Statistics

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| Min Duration   | 7  | 2 Jan 1997 06:56:24.43 | 2 Jan 1997 06:58:39.81 | 135.376 |
| Max Duration   | 35 | 9 Jan 1997 04:35:36.12 | 9 Jan 1997 04:46:49.56 | 673.445 |
| Mean Duration  |    |                        | 521.518                |         |
| Total Duration |    |                        | 19817.686              |         |

Latitude -55 degrees Elevation 10 degrees

11 Apr 1998 14:07:39

Chain-Sat\_ground\_lat\_neg55: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| 1      | 1 Jan 1997 07:44:00.95 | 1 Jan 1997 07:49:55.67 | 354.715        |
| 2      | 1 Jan 1997 09:20:48.79 | 1 Jan 1997 09:32:59.79 | 731.003        |
| 3      | 1 Jan 1997 11:01:21.57 | 1 Jan 1997 11:13:51.26 | 749.690        |
| 4      | 1 Jan 1997 12:45:27.55 | 1 Jan 1997 12:52:52.10 | 444.545        |
| 5      | 1 Jan 1997 19:44:56.05 | 1 Jan 1997 19:55:23.50 | 627.444        |
| 6      | 1 Jan 1997 21:24:59.90 | 1 Jan 1997 21:37:55.35 | 775.450        |
| 7      | 1 Jan 1997 23:06:27.08 | 1 Jan 1997 23:16:60.00 | 632.917        |
| 8      | 2 Jan 1997 08:47:47.01 | 2 Jan 1997 08:58:56.29 | 669.283        |
| 9      | 2 Jan 1997 10:27:18.72 | 2 Jan 1997 10:40:11.61 | 772.896        |
| 10     | 2 Jan 1997 12:10:18.05 | 2 Jan 1997 12:20:01.38 | 583.333        |
| 11     | 2 Jan 1997 19:11:51.45 | 2 Jan 1997 19:20:23.58 | 512.124        |
| 12     | 2 Jan 1997 20:51:17.48 | 2 Jan 1997 21:04:00.19 | 762.715        |
| 13     | 2 Jan 1997 22:32:18.84 | 2 Jan 1997 22:44:06.80 | 707.951        |
| 14     | 3 Jan 1997 00:16:21.65 | 3 Jan 1997 00:20:17.27 | 235.615        |
| 15     | 3 Jan 1997 08:15:05.79 | 3 Jan 1997 08:24:40.06 | 574.267        |
| 16     | 3 Jan 1997 09:53:33.61 | 3 Jan 1997 10:06:25.65 | 772.047        |
| 17     | 3 Jan 1997 11:35:30.10 | 3 Jan 1997 11:46:45.10 | 675.003        |
| 18     | 3 Jan 1997 18:39:37.36 | 3 Jan 1997 18:45:00.60 | 323.243        |
| 19     | 3 Jan 1997 20:17:41.81 | 3 Jan 1997 20:29:47.07 | 725.260        |
| 20     | 3 Jan 1997 21:58:20.49 | 3 Jan 1997 22:10:54.21 | 753.723        |
| 21     | 3 Jan 1997 23:40:42.69 | 3 Jan 1997 23:48:25.85 | 463.153        |
| 22     | 4 Jan 1997 07:42:48.76 | 4 Jan 1997 07:49:59.34 | 430.587        |
| 23     | 4 Jan 1997 09:20:06.25 | 4 Jan 1997 09:32:33.30 | 747.052        |
| 24     | 4 Jan 1997 11:01:01.89 | 4 Jan 1997 11:13:16.27 | 734.384        |
| 25     | 4 Jan 1997 12:45:34.54 | 4 Jan 1997 12:51:44.62 | 370.080        |
| 26     | 4 Jan 1997 19:44:14.90 | 4 Jan 1997 19:55:15.21 | 660.306        |
| 27     | 4 Jan 1997 21:24:29.41 | 4 Jan 1997 21:37:23.45 | 774.044        |
| 28     | 4 Jan 1997 23:06:08.39 | 4 Jan 1997 23:16:03.78 | 595.393        |
| 29     | 5 Jan 1997 07:11:18.92 | 5 Jan 1997 07:13:34.17 | 135.247        |
| 30     | 5 Jan 1997 08:46:57.23 | 5 Jan 1997 08:58:33.34 | 696.103        |
| 31     | 5 Jan 1997 10:26:52.23 | 5 Jan 1997 10:39:39.22 | 766.994        |
| 32     | 5 Jan 1997 12:10:16.21 | 5 Jan 1997 12:19:14.08 | 537.871        |
| 33     | 5 Jan 1997 19:11:01.98 | 5 Jan 1997 19:20:23.33 | 561.342        |
| 34     | 5 Jan 1997 20:50:44.63 | 5 Jan 1997 21:03:34.98 | 770.358        |
| 35     | 5 Jan 1997 22:31:55.11 | 5 Jan 1997 22:43:18.44 | 683.334        |
| 36     | 6 Jan 1997 08:14:07.94 | 6 Jan 1997 08:24:22.69 | 614.748        |
| 37     | 6 Jan 1997 09:53:00.44 | 6 Jan 1997 10:05:55.60 | 775.168        |
| 38     | 6 Jan 1997 11:35:20.36 | 6 Jan 1997 11:46:04.97 | 644.604        |



|    |                        |                        |         |
|----|------------------------|------------------------|---------|
| 39 | 6 Jan 1997 18:38:20.01 | 6 Jan 1997 18:45:09.44 | 409.426 |
| 40 | 6 Jan 1997 20:17:06.26 | 6 Jan 1997 20:29:28.72 | 742.454 |
| 41 | 6 Jan 1997 21:57:53.45 | 6 Jan 1997 22:10:13.00 | 739.547 |
| 42 | 6 Jan 1997 23:40:41.00 | 6 Jan 1997 23:47:16.04 | 395.036 |
| 43 | 7 Jan 1997 07:41:41.14 | 7 Jan 1997 07:49:53.66 | 492.525 |
| 44 | 7 Jan 1997 09:19:26.33 | 7 Jan 1997 09:32:05.74 | 759.415 |
| 45 | 7 Jan 1997 11:00:44.86 | 7 Jan 1997 11:12:40.14 | 715.279 |
| 46 | 7 Jan 1997 12:46:15.76 | 7 Jan 1997 12:50:09.43 | 233.666 |
| 47 | 7 Jan 1997 19:43:35.67 | 7 Jan 1997 19:55:04.06 | 688.395 |
| 48 | 7 Jan 1997 21:23:59.80 | 7 Jan 1997 21:36:49.02 | 769.221 |
| 49 | 7 Jan 1997 23:05:52.52 | 7 Jan 1997 23:15:04.27 | 551.749 |
| 50 | 8 Jan 1997 07:09:42.96 | 8 Jan 1997 07:14:36.98 | 294.016 |
| 51 | 8 Jan 1997 08:46:10.26 | 8 Jan 1997 08:58:08.89 | 718.627 |
| 52 | 8 Jan 1997 10:26:28.29 | 8 Jan 1997 10:39:05.90 | 757.615 |
| 53 | 8 Jan 1997 12:10:17.56 | 8 Jan 1997 12:18:22.01 | 484.445 |
| 54 | 8 Jan 1997 19:10:16.47 | 8 Jan 1997 19:20:19.94 | 603.472 |
| 55 | 8 Jan 1997 20:50:12.68 | 8 Jan 1997 21:03:07.23 | 774.554 |
| 56 | 8 Jan 1997 22:31:32.99 | 8 Jan 1997 22:42:27.23 | 654.241 |
| 57 | 9 Jan 1997 08:13:13.28 | 9 Jan 1997 08:24:02.83 | 649.547 |
| 58 | 9 Jan 1997 09:52:29.79 | 9 Jan 1997 10:05:24.67 | 774.884 |
| 59 | 9 Jan 1997 11:35:13.53 | 9 Jan 1997 11:45:22.69 | 609.164 |
| 60 | 9 Jan 1997 18:37:18.92 | 9 Jan 1997 18:45:14.67 | 475.745 |
| 61 | 9 Jan 1997 20:16:31.81 | 9 Jan 1997 20:29:07.74 | 755.933 |
| 62 | 9 Jan 1997 21:57:27.54 | 9 Jan 1997 22:09:29.14 | 721.604 |
| 63 | 9 Jan 1997 23:40:52.20 | 9 Jan 1997 23:46:01.26 | 309.062 |

#### Global Statistics

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| Min Duration   | 29 | 5 Jan 1997 07:11:18.92 | 5 Jan 1997 07:13:34.17 | 135.247 |
| Max Duration   | 6  | 1 Jan 1997 21:24:59.90 | 1 Jan 1997 21:37:55.35 | 775.450 |
| Mean Duration  |    |                        | 609.899                |         |
| Total Duration |    |                        | 38423.613              |         |

Latitude -55 degrees Elevation 15 degrees

11 Apr 1998 14:03:59

Chain-Sat\_ground\_lat\_neg55: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| 1      | 1 Jan 1997 07:44:00.95 | 1 Jan 1997 07:48:37.79 | 276.840        |
| 2      | 1 Jan 1997 09:20:48.79 | 1 Jan 1997 09:32:07.37 | 678.587        |
| 3      | 1 Jan 1997 11:01:21.57 | 1 Jan 1997 11:12:55.83 | 694.266        |
| 4      | 1 Jan 1997 12:45:27.55 | 1 Jan 1997 12:51:14.43 | 346.876        |
| 5      | 1 Jan 1997 19:46:04.16 | 1 Jan 1997 19:55:23.50 | 559.338        |
| 6      | 1 Jan 1997 21:25:51.98 | 1 Jan 1997 21:37:55.35 | 723.372        |
| 7      | 1 Jan 1997 23:07:23.77 | 1 Jan 1997 23:16:60.00 | 576.229        |
| 8      | 2 Jan 1997 08:47:47.01 | 2 Jan 1997 08:58:01.37 | 614.359        |
| 9      | 2 Jan 1997 10:27:18.72 | 2 Jan 1997 10:39:18.88 | 720.163        |
| 10     | 2 Jan 1997 12:10:18.05 | 2 Jan 1997 12:18:47.85 | 509.798        |
| 11     | 2 Jan 1997 19:13:15.58 | 2 Jan 1997 19:20:23.58 | 427.993        |
| 12     | 2 Jan 1997 20:52:11.52 | 2 Jan 1997 21:04:00.19 | 708.671        |
| 13     | 2 Jan 1997 22:33:12.11 | 2 Jan 1997 22:44:06.80 | 654.686        |
| 14     | 3 Jan 1997 00:18:00.84 | 3 Jan 1997 00:20:17.27 | 136.427        |
| 15     | 3 Jan 1997 08:15:05.79 | 3 Jan 1997 08:23:40.14 | 514.356        |
| 16     | 3 Jan 1997 09:53:33.61 | 3 Jan 1997 10:05:34.03 | 720.423        |
| 17     | 3 Jan 1997 11:35:30.10 | 3 Jan 1997 11:45:42.21 | 612.108        |
| 18     | 3 Jan 1997 18:42:07.74 | 3 Jan 1997 18:45:00.60 | 172.862        |
| 19     | 3 Jan 1997 20:18:39.66 | 3 Jan 1997 20:29:47.07 | 667.412        |
| 20     | 3 Jan 1997 21:59:12.24 | 3 Jan 1997 22:10:54.21 | 701.967        |
| 21     | 3 Jan 1997 23:41:50.19 | 3 Jan 1997 23:48:25.85 | 395.658        |
| 22     | 4 Jan 1997 07:42:48.76 | 4 Jan 1997 07:48:49.14 | 360.382        |
| 23     | 4 Jan 1997 09:20:06.25 | 4 Jan 1997 09:31:41.38 | 695.130        |
| 24     | 4 Jan 1997 11:01:01.89 | 4 Jan 1997 11:12:19.32 | 677.433        |
| 25     | 4 Jan 1997 12:45:34.54 | 4 Jan 1997 12:49:43.32 | 248.774        |
| 26     | 4 Jan 1997 19:45:19.35 | 4 Jan 1997 19:55:15.21 | 595.858        |
| 27     | 4 Jan 1997 21:25:21.13 | 4 Jan 1997 21:37:23.45 | 722.319        |
| 28     | 4 Jan 1997 23:07:07.08 | 4 Jan 1997 23:16:03.78 | 536.698        |
| 29     | 5 Jan 1997 08:46:57.23 | 5 Jan 1997 08:57:39.59 | 642.356        |
| 30     | 5 Jan 1997 10:26:52.23 | 5 Jan 1997 10:38:45.67 | 713.449        |
| 31     | 5 Jan 1997 12:10:16.21 | 5 Jan 1997 12:17:54.10 | 457.894        |
| 32     | 5 Jan 1997 19:12:18.51 | 5 Jan 1997 19:20:23.33 | 484.816        |
| 33     | 5 Jan 1997 20:51:37.74 | 5 Jan 1997 21:03:34.98 | 717.245        |
| 34     | 5 Jan 1997 22:32:49.40 | 5 Jan 1997 22:43:18.44 | 629.040        |
| 35     | 6 Jan 1997 08:14:07.94 | 6 Jan 1997 08:23:25.06 | 557.112        |
| 36     | 6 Jan 1997 09:53:00.44 | 6 Jan 1997 10:05:03.73 | 723.293        |
| 37     | 6 Jan 1997 11:35:20.36 | 6 Jan 1997 11:44:58.81 | 578.444        |
| 38     | 6 Jan 1997 18:40:07.10 | 6 Jan 1997 18:45:09.44 | 302.336        |

|    |                        |                        |         |
|----|------------------------|------------------------|---------|
| 39 | 6 Jan 1997 20:18:02.41 | 6 Jan 1997 20:29:28.72 | 686.303 |
| 40 | 6 Jan 1997 21:58:45.59 | 6 Jan 1997 22:10:13.00 | 687.407 |
| 41 | 6 Jan 1997 23:41:54.52 | 6 Jan 1997 23:47:16.04 | 321.518 |
| 42 | 7 Jan 1997 07:41:41.14 | 7 Jan 1997 07:48:48.40 | 427.258 |
| 43 | 7 Jan 1997 09:19:26.33 | 7 Jan 1997 09:31:14.10 | 707.772 |
| 44 | 7 Jan 1997 11:00:44.86 | 7 Jan 1997 11:11:41.31 | 656.449 |
| 45 | 7 Jan 1997 19:44:37.19 | 7 Jan 1997 19:55:04.06 | 626.877 |
| 46 | 7 Jan 1997 21:24:51.38 | 7 Jan 1997 21:36:49.02 | 717.648 |
| 47 | 7 Jan 1997 23:06:53.80 | 7 Jan 1997 23:15:04.27 | 490.472 |
| 48 | 8 Jan 1997 07:09:42.96 | 8 Jan 1997 07:13:10.62 | 207.664 |
| 49 | 8 Jan 1997 08:46:10.26 | 8 Jan 1997 08:57:16.04 | 665.771 |
| 50 | 8 Jan 1997 10:26:28.29 | 8 Jan 1997 10:38:11.30 | 703.015 |
| 51 | 8 Jan 1997 12:10:17.56 | 8 Jan 1997 12:16:52.87 | 395.310 |
| 52 | 8 Jan 1997 19:11:27.44 | 8 Jan 1997 19:20:19.94 | 532.500 |
| 53 | 8 Jan 1997 20:51:05.09 | 8 Jan 1997 21:03:07.23 | 722.140 |
| 54 | 8 Jan 1997 22:32:28.62 | 8 Jan 1997 22:42:27.23 | 598.610 |
| 55 | 9 Jan 1997 08:13:13.28 | 9 Jan 1997 08:23:06.97 | 593.688 |
| 56 | 9 Jan 1997 09:52:29.79 | 9 Jan 1997 10:04:32.34 | 722.555 |
| 57 | 9 Jan 1997 11:35:13.53 | 9 Jan 1997 11:44:12.42 | 538.890 |
| 58 | 9 Jan 1997 18:38:49.77 | 9 Jan 1997 18:45:14.67 | 384.900 |
| 59 | 9 Jan 1997 20:17:26.59 | 9 Jan 1997 20:29:07.74 | 701.155 |
| 60 | 9 Jan 1997 21:58:20.29 | 9 Jan 1997 22:09:29.14 | 668.857 |
| 61 | 9 Jan 1997 23:42:16.16 | 9 Jan 1997 23:46:01.26 | 225.107 |

#### Global Statistics

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| Min Duration   | 14 | 3 Jan 1997 00:18:00.84 | 3 Jan 1997 00:20:17.27 | 136.427 |
| Max Duration   | 6  | 1 Jan 1997 21:25:51.98 | 1 Jan 1997 21:37:55.35 | 723.372 |
| Mean Duration  |    |                        | 557.981                |         |
| Total Duration |    |                        | 34036.837              |         |

Latitude -55 degrees Elevation 20 degrees

11 Apr 1998 14:09:55

Chain-Sat\_ground\_lat\_neg55: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| 1      | 1 Jan 1997 07:44:00.95 | 1 Jan 1997 07:47:45.39 | 224.434        |
| 2      | 1 Jan 1997 09:20:48.79 | 1 Jan 1997 09:31:25.31 | 636.523        |
| 3      | 1 Jan 1997 11:01:21.57 | 1 Jan 1997 11:12:10.94 | 649.377        |
| 4      | 1 Jan 1997 12:45:27.55 | 1 Jan 1997 12:50:01.00 | 273.451        |
| 5      | 1 Jan 1997 19:46:58.32 | 1 Jan 1997 19:55:23.50 | 505.179        |
| 6      | 1 Jan 1997 21:26:34.21 | 1 Jan 1997 21:37:55.35 | 681.143        |
| 7      | 1 Jan 1997 23:08:08.22 | 1 Jan 1997 23:16:60.00 | 531.776        |
| 8      | 2 Jan 1997 08:47:47.01 | 2 Jan 1997 08:57:17.90 | 570.886        |
| 9      | 2 Jan 1997 10:27:18.72 | 2 Jan 1997 10:38:36.10 | 677.385        |
| 10     | 2 Jan 1997 12:10:18.05 | 2 Jan 1997 12:17:49.93 | 451.880        |
| 11     | 2 Jan 1997 19:14:20.52 | 2 Jan 1997 19:20:23.58 | 363.052        |
| 12     | 2 Jan 1997 20:52:55.34 | 2 Jan 1997 21:04:00.19 | 664.850        |
| 13     | 2 Jan 1997 22:33:54.65 | 2 Jan 1997 22:44:06.80 | 612.149        |
| 14     | 3 Jan 1997 00:18:51.97 | 3 Jan 1997 00:20:17.27 | 85.301         |
| 15     | 3 Jan 1997 08:15:05.79 | 3 Jan 1997 08:22:53.99 | 468.203        |
| 16     | 3 Jan 1997 09:53:33.61 | 3 Jan 1997 10:04:52.23 | 678.623        |
| 17     | 3 Jan 1997 11:35:30.10 | 3 Jan 1997 11:44:51.77 | 561.666        |
| 18     | 3 Jan 1997 18:43:58.37 | 3 Jan 1997 18:45:00.60 | 62.235         |
| 19     | 3 Jan 1997 20:19:26.38 | 3 Jan 1997 20:29:47.07 | 620.686        |
| 20     | 3 Jan 1997 21:59:53.98 | 3 Jan 1997 22:10:54.21 | 660.236        |
| 21     | 3 Jan 1997 23:42:39.72 | 3 Jan 1997 23:48:25.85 | 346.125        |
| 22     | 4 Jan 1997 07:42:48.76 | 4 Jan 1997 07:47:58.65 | 309.890        |
| 23     | 4 Jan 1997 09:20:06.25 | 4 Jan 1997 09:30:59.57 | 653.322        |
| 24     | 4 Jan 1997 11:01:01.89 | 4 Jan 1997 11:11:33.27 | 631.383        |
| 25     | 4 Jan 1997 12:45:34.54 | 4 Jan 1997 12:48:15.47 | 160.928        |
| 26     | 4 Jan 1997 19:46:10.91 | 4 Jan 1997 19:55:15.21 | 544.296        |
| 27     | 4 Jan 1997 21:26:03.04 | 4 Jan 1997 21:37:23.45 | 680.410        |
| 28     | 4 Jan 1997 23:07:52.61 | 4 Jan 1997 23:16:03.78 | 491.170        |
| 29     | 5 Jan 1997 08:46:57.23 | 5 Jan 1997 08:56:56.78 | 599.548        |
| 30     | 5 Jan 1997 10:26:52.23 | 5 Jan 1997 10:38:02.25 | 670.020        |
| 31     | 5 Jan 1997 12:10:16.21 | 5 Jan 1997 12:16:51.87 | 395.661        |
| 32     | 5 Jan 1997 19:13:18.45 | 5 Jan 1997 19:20:23.33 | 424.876        |
| 33     | 5 Jan 1997 20:52:20.82 | 5 Jan 1997 21:03:34.98 | 674.160        |
| 34     | 5 Jan 1997 22:33:32.52 | 5 Jan 1997 22:43:18.44 | 585.923        |
| 35     | 6 Jan 1997 08:14:07.94 | 6 Jan 1997 08:22:40.09 | 512.145        |
| 36     | 6 Jan 1997 09:53:00.44 | 6 Jan 1997 10:04:21.68 | 681.243        |
| 37     | 6 Jan 1997 11:35:20.36 | 6 Jan 1997 11:44:06.02 | 525.659        |
| 38     | 6 Jan 1997 18:41:26.24 | 6 Jan 1997 18:45:09.44 | 223.195        |

|    |                        |                        |         |
|----|------------------------|------------------------|---------|
| 39 | 6 Jan 1997 20:18:47.86 | 6 Jan 1997 20:29:28.72 | 640.858 |
| 40 | 6 Jan 1997 21:59:27.51 | 6 Jan 1997 22:10:13.00 | 645.490 |
| 41 | 6 Jan 1997 23:42:45.99 | 6 Jan 1997 23:47:16.04 | 270.049 |
| 42 | 7 Jan 1997 07:41:41.14 | 7 Jan 1997 07:47:59.75 | 378.616 |
| 43 | 7 Jan 1997 09:19:26.33 | 7 Jan 1997 09:30:32.41 | 666.080 |
| 44 | 7 Jan 1997 11:00:44.86 | 7 Jan 1997 11:10:53.85 | 608.991 |
| 45 | 7 Jan 1997 19:45:26.63 | 7 Jan 1997 19:55:04.06 | 577.438 |
| 46 | 7 Jan 1997 21:25:33.10 | 7 Jan 1997 21:36:49.02 | 675.919 |
| 47 | 7 Jan 1997 23:07:40.63 | 7 Jan 1997 23:15:04.27 | 443.641 |
| 48 | 8 Jan 1997 07:09:42.96 | 8 Jan 1997 07:12:17.58 | 154.619 |
| 49 | 8 Jan 1997 08:46:10.26 | 8 Jan 1997 08:56:33.73 | 623.464 |
| 50 | 8 Jan 1997 10:26:28.29 | 8 Jan 1997 10:37:27.05 | 658.760 |
| 51 | 8 Jan 1997 12:10:17.56 | 8 Jan 1997 12:15:44.74 | 327.180 |
| 52 | 8 Jan 1997 19:12:23.60 | 8 Jan 1997 19:20:19.94 | 476.343 |
| 53 | 8 Jan 1997 20:51:47.61 | 8 Jan 1997 21:03:07.23 | 679.625 |
| 54 | 8 Jan 1997 22:33:12.49 | 8 Jan 1997 22:42:27.23 | 554.740 |
| 55 | 9 Jan 1997 08:13:13.28 | 9 Jan 1997 08:22:22.98 | 549.692 |
| 56 | 9 Jan 1997 09:52:29.79 | 9 Jan 1997 10:03:49.90 | 680.111 |
| 57 | 9 Jan 1997 11:35:13.53 | 9 Jan 1997 11:43:16.74 | 483.216 |
| 58 | 9 Jan 1997 18:39:58.97 | 9 Jan 1997 18:45:14.67 | 315.695 |
| 59 | 9 Jan 1997 20:18:10.98 | 9 Jan 1997 20:29:07.74 | 656.762 |
| 60 | 9 Jan 1997 21:59:02.53 | 9 Jan 1997 22:09:29.14 | 626.612 |
| 61 | 9 Jan 1997 23:43:09.18 | 9 Jan 1997 23:46:01.26 | 172.083 |

#### Global Statistics

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| -----          |    |                        |                        |         |
| Min Duration   | 18 | 3 Jan 1997 18:43:58.37 | 3 Jan 1997 18:45:00.60 | 62.235  |
| Max Duration   | 36 | 6 Jan 1997 09:53:00.44 | 6 Jan 1997 10:04:21.68 | 681.243 |
| Mean Duration  |    |                        | 507.459                |         |
| Total Duration |    |                        | 30954.972              |         |

Latitude 55 degrees Elevation 10 degrees  
 11 Apr 1998 14:07:03  
 Chain-Sat\_ground\_lat55: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| -----  | -----                  | -----                  | -----          |
| 1      | 1 Jan 1997 00:10:59.10 | 1 Jan 1997 00:22:36.64 | 697.540        |
| 2      | 1 Jan 1997 01:50:45.55 | 1 Jan 1997 02:03:44.01 | 778.466        |
| 3      | 1 Jan 1997 03:32:37.08 | 1 Jan 1997 03:44:22.93 | 705.855        |
| 4      | 1 Jan 1997 05:18:27.12 | 1 Jan 1997 05:24:05.90 | 338.775        |
| 5      | 1 Jan 1997 10:29:30.31 | 1 Jan 1997 10:40:34.82 | 664.515        |
| 6      | 1 Jan 1997 12:10:01.86 | 1 Jan 1997 12:22:55.94 | 774.077        |
| 7      | 1 Jan 1997 13:51:00.83 | 1 Jan 1997 14:03:14.41 | 733.587        |
| 8      | 1 Jan 1997 15:32:56.75 | 1 Jan 1997 15:41:25.21 | 508.453        |
| 9      | 1 Jan 1997 23:37:55.68 | 1 Jan 1997 23:48:35.16 | 639.484        |
| 10     | 2 Jan 1997 01:17:04.23 | 2 Jan 1997 01:29:55.58 | 771.350        |
| 11     | 2 Jan 1997 02:58:19.59 | 2 Jan 1997 03:10:42.21 | 742.615        |
| 12     | 2 Jan 1997 04:42:10.77 | 2 Jan 1997 04:50:53.84 | 523.069        |
| 13     | 2 Jan 1997 09:55:57.31 | 2 Jan 1997 10:05:54.89 | 597.580        |
| 14     | 2 Jan 1997 11:36:17.47 | 2 Jan 1997 11:48:54.37 | 756.898        |
| 15     | 2 Jan 1997 13:17:08.15 | 2 Jan 1997 13:29:50.21 | 762.055        |
| 16     | 2 Jan 1997 14:58:37.83 | 2 Jan 1997 15:08:38.71 | 600.881        |
| 17     | 2 Jan 1997 23:05:03.38 | 2 Jan 1997 23:14:24.40 | 561.019        |
| 18     | 3 Jan 1997 00:43:34.08 | 3 Jan 1997 00:56:04.55 | 750.465        |
| 19     | 3 Jan 1997 02:24:12.39 | 3 Jan 1997 02:36:58.98 | 766.592        |
| 20     | 3 Jan 1997 04:06:51.19 | 3 Jan 1997 04:17:25.05 | 633.857        |
| 21     | 3 Jan 1997 09:22:34.18 | 3 Jan 1997 09:29:59.58 | 445.404        |
| 22     | 3 Jan 1997 11:02:35.36 | 3 Jan 1997 11:14:42.26 | 726.900        |
| 23     | 3 Jan 1997 12:43:18.41 | 3 Jan 1997 12:56:14.79 | 776.380        |
| 24     | 3 Jan 1997 14:24:32.12 | 3 Jan 1997 14:35:41.19 | 669.071        |
| 25     | 3 Jan 1997 16:08:33.40 | 3 Jan 1997 16:10:27.53 | 114.127        |
| 26     | 3 Jan 1997 22:32:36.00 | 3 Jan 1997 22:39:54.03 | 438.037        |
| 27     | 4 Jan 1997 00:10:15.17 | 4 Jan 1997 00:22:10.17 | 715.006        |
| 28     | 4 Jan 1997 01:50:15.90 | 4 Jan 1997 02:03:13.58 | 777.679        |
| 29     | 4 Jan 1997 03:32:20.77 | 4 Jan 1997 03:43:49.38 | 688.607        |
| 30     | 4 Jan 1997 05:19:10.92 | 4 Jan 1997 05:23:09.37 | 238.451        |
| 31     | 4 Jan 1997 08:49:44.65 | 4 Jan 1997 08:53:12.07 | 207.418        |
| 32     | 4 Jan 1997 10:28:56.06 | 4 Jan 1997 10:40:20.15 | 684.096        |
| 33     | 4 Jan 1997 12:09:31.05 | 4 Jan 1997 12:22:28.25 | 777.199        |
| 34     | 4 Jan 1997 13:50:33.55 | 4 Jan 1997 14:02:32.48 | 718.936        |
| 35     | 4 Jan 1997 15:32:45.04 | 4 Jan 1997 15:40:22.74 | 457.703        |
| 36     | 4 Jan 1997 23:37:07.50 | 4 Jan 1997 23:48:11.08 | 663.577        |
| 37     | 5 Jan 1997 01:16:30.39 | 5 Jan 1997 01:29:26.02 | 775.628        |
| 38     | 5 Jan 1997 02:57:59.56 | 5 Jan 1997 03:10:09.78 | 730.217        |

|    |                        |                        |         |
|----|------------------------|------------------------|---------|
| 39 | 5 Jan 1997 04:42:31.60 | 5 Jan 1997 04:50:13.32 | 461.721 |
| 40 | 5 Jan 1997 09:55:20.85 | 5 Jan 1997 10:05:48.93 | 628.080 |
| 41 | 5 Jan 1997 11:35:45.85 | 5 Jan 1997 11:48:30.76 | 764.909 |
| 42 | 5 Jan 1997 13:16:39.53 | 5 Jan 1997 13:29:12.53 | 752.998 |
| 43 | 5 Jan 1997 14:58:17.40 | 5 Jan 1997 15:07:46.73 | 569.323 |
| 44 | 5 Jan 1997 23:04:11.02 | 5 Jan 1997 23:14:04.49 | 593.477 |
| 45 | 6 Jan 1997 00:42:56.01 | 6 Jan 1997 00:55:36.03 | 760.024 |
| 46 | 6 Jan 1997 02:23:48.41 | 6 Jan 1997 02:36:27.44 | 759.031 |
| 47 | 6 Jan 1997 04:06:39.38 | 6 Jan 1997 04:16:48.86 | 609.481 |
| 48 | 6 Jan 1997 09:21:52.99 | 6 Jan 1997 09:30:21.73 | 508.739 |
| 49 | 6 Jan 1997 11:02:02.84 | 6 Jan 1997 11:14:22.58 | 739.746 |
| 50 | 6 Jan 1997 12:42:48.76 | 6 Jan 1997 12:55:41.34 | 772.579 |
| 51 | 6 Jan 1997 14:24:07.76 | 6 Jan 1997 14:34:53.40 | 645.642 |
| 52 | 6 Jan 1997 22:31:25.52 | 6 Jan 1997 22:39:43.72 | 498.200 |
| 53 | 7 Jan 1997 00:09:32.84 | 7 Jan 1997 00:21:43.04 | 730.199 |
| 54 | 7 Jan 1997 01:49:47.83 | 7 Jan 1997 02:02:42.84 | 775.015 |
| 55 | 7 Jan 1997 03:32:05.78 | 7 Jan 1997 03:43:15.27 | 669.490 |
| 56 | 7 Jan 1997 05:20:45.52 | 7 Jan 1997 05:21:24.51 | 38.990  |
| 57 | 7 Jan 1997 08:48:43.88 | 7 Jan 1997 08:54:00.72 | 316.843 |
| 58 | 7 Jan 1997 10:28:22.37 | 7 Jan 1997 10:40:04.17 | 701.799 |
| 59 | 7 Jan 1997 12:09:00.54 | 7 Jan 1997 12:21:58.99 | 778.448 |
| 60 | 7 Jan 1997 13:50:06.91 | 7 Jan 1997 14:01:48.94 | 702.036 |
| 61 | 7 Jan 1997 15:32:40.51 | 7 Jan 1997 15:38:50.29 | 369.780 |
| 62 | 7 Jan 1997 22:00:15.89 | 7 Jan 1997 22:04:41.11 | 265.222 |
| 63 | 7 Jan 1997 23:36:20.92 | 7 Jan 1997 23:47:45.96 | 685.032 |
| 64 | 8 Jan 1997 01:15:58.14 | 8 Jan 1997 01:28:56.11 | 777.970 |
| 65 | 8 Jan 1997 02:57:40.97 | 8 Jan 1997 03:09:36.96 | 715.993 |
| 66 | 8 Jan 1997 04:42:58.36 | 8 Jan 1997 04:49:29.54 | 391.178 |
| 67 | 8 Jan 1997 09:54:45.39 | 8 Jan 1997 10:05:36.27 | 650.879 |
| 68 | 8 Jan 1997 11:35:14.54 | 8 Jan 1997 11:48:05.62 | 771.080 |
| 69 | 8 Jan 1997 13:16:11.37 | 8 Jan 1997 13:28:33.24 | 741.875 |
| 70 | 8 Jan 1997 14:57:59.36 | 8 Jan 1997 15:06:53.18 | 533.827 |
| 71 | 8 Jan 1997 23:03:20.22 | 8 Jan 1997 23:13:42.68 | 622.455 |
| 72 | 9 Jan 1997 00:42:19.54 | 9 Jan 1997 00:55:07.09 | 767.553 |
| 73 | 9 Jan 1997 02:23:25.94 | 9 Jan 1997 02:35:55.57 | 749.637 |
| 74 | 9 Jan 1997 04:06:52.61 | 9 Jan 1997 04:16:11.45 | 558.841 |
| 75 | 9 Jan 1997 09:21:14.13 | 9 Jan 1997 09:30:38.84 | 564.715 |
| 76 | 9 Jan 1997 11:01:30.67 | 9 Jan 1997 11:14:01.44 | 750.765 |
| 77 | 9 Jan 1997 12:42:19.47 | 9 Jan 1997 12:55:06.29 | 766.820 |
| 78 | 9 Jan 1997 14:23:44.62 | 9 Jan 1997 14:34:04.02 | 619.408 |
| 79 | 9 Jan 1997 22:30:30.61 | 9 Jan 1997 22:39:28.58 | 537.971 |

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| -----          |    |                        |                        |         |
| Min Duration   | 56 | 7 Jan 1997 05:20:45.52 | 7 Jan 1997 05:21:24.51 | 38.990  |
| Max Duration   | 2  | 1 Jan 1997 01:50:45.55 | 1 Jan 1997 02:03:44.01 | 778.466 |
| Mean Duration  |    |                        | 626.954                |         |
| Total Duration |    |                        | 49529.341              |         |



Latitude 55 degrees Elevation 15 degrees  
 11 Apr 1998 14:02:08  
 Chain-Sat\_ground\_lat55: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| -----  | -----                  | -----                  | -----          |
| 1      | 1 Jan 1997 00:11:38.73 | 1 Jan 1997 00:22:36.64 | 657.915        |
| 2      | 1 Jan 1997 01:51:36.07 | 1 Jan 1997 02:03:44.01 | 727.942        |
| 3      | 1 Jan 1997 03:33:03.38 | 1 Jan 1997 03:44:22.93 | 679.556        |
| 4      | 1 Jan 1997 05:18:27.12 | 1 Jan 1997 05:24:05.90 | 338.775        |
| 5      | 1 Jan 1997 10:29:30.31 | 1 Jan 1997 10:40:20.12 | 649.815        |
| 6      | 1 Jan 1997 12:10:01.86 | 1 Jan 1997 12:22:08.21 | 726.350        |
| 7      | 1 Jan 1997 13:51:00.83 | 1 Jan 1997 14:02:28.62 | 687.796        |
| 8      | 1 Jan 1997 15:32:56.75 | 1 Jan 1997 15:41:19.53 | 502.779        |
| 9      | 1 Jan 1997 23:38:24.82 | 1 Jan 1997 23:48:35.16 | 610.343        |
| 10     | 2 Jan 1997 01:17:55.24 | 2 Jan 1997 01:29:55.58 | 720.335        |
| 11     | 2 Jan 1997 02:58:56.73 | 2 Jan 1997 03:10:42.21 | 705.481        |
| 12     | 2 Jan 1997 04:42:10.77 | 2 Jan 1997 04:50:53.84 | 523.069        |
| 13     | 2 Jan 1997 09:55:57.31 | 2 Jan 1997 10:05:54.89 | 597.580        |
| 14     | 2 Jan 1997 11:36:17.47 | 2 Jan 1997 11:48:12.75 | 715.283        |
| 15     | 2 Jan 1997 13:17:08.15 | 2 Jan 1997 13:29:00.17 | 712.019        |
| 16     | 2 Jan 1997 14:58:37.83 | 2 Jan 1997 15:08:16.62 | 578.795        |
| 17     | 2 Jan 1997 23:05:18.26 | 2 Jan 1997 23:14:24.40 | 546.142        |
| 18     | 3 Jan 1997 00:44:22.52 | 3 Jan 1997 00:56:04.55 | 702.032        |
| 19     | 3 Jan 1997 02:24:57.26 | 3 Jan 1997 02:36:58.98 | 721.717        |
| 20     | 3 Jan 1997 04:06:57.59 | 3 Jan 1997 04:17:25.05 | 627.455        |
| 21     | 3 Jan 1997 09:22:34.18 | 3 Jan 1997 09:29:59.58 | 445.404        |
| 22     | 3 Jan 1997 11:02:35.36 | 3 Jan 1997 11:14:09.84 | 694.482        |
| 23     | 3 Jan 1997 12:43:18.41 | 3 Jan 1997 12:55:23.63 | 725.217        |
| 24     | 3 Jan 1997 14:24:32.12 | 3 Jan 1997 14:35:06.66 | 634.544        |
| 25     | 3 Jan 1997 16:08:33.40 | 3 Jan 1997 16:10:27.53 | 114.127        |
| 26     | 3 Jan 1997 22:32:36.00 | 3 Jan 1997 22:39:54.03 | 438.037        |
| 27     | 4 Jan 1997 00:10:57.84 | 4 Jan 1997 00:22:10.17 | 672.335        |
| 28     | 4 Jan 1997 01:51:05.45 | 4 Jan 1997 02:03:13.58 | 728.130        |
| 29     | 4 Jan 1997 03:32:42.17 | 4 Jan 1997 03:43:49.38 | 667.207        |
| 30     | 4 Jan 1997 05:19:10.92 | 4 Jan 1997 05:23:09.37 | 238.451        |
| 31     | 4 Jan 1997 08:49:44.65 | 4 Jan 1997 08:53:12.07 | 207.418        |
| 32     | 4 Jan 1997 10:28:56.06 | 4 Jan 1997 10:40:00.02 | 663.962        |
| 33     | 4 Jan 1997 12:09:31.05 | 4 Jan 1997 12:21:39.01 | 727.956        |
| 34     | 4 Jan 1997 13:50:33.55 | 4 Jan 1997 14:01:49.14 | 675.593        |
| 35     | 4 Jan 1997 15:32:45.04 | 4 Jan 1997 15:40:22.74 | 457.703        |
| 36     | 4 Jan 1997 23:37:41.03 | 4 Jan 1997 23:48:11.08 | 630.046        |
| 37     | 5 Jan 1997 01:17:21.58 | 5 Jan 1997 01:29:26.02 | 724.441        |
| 38     | 5 Jan 1997 02:58:32.96 | 5 Jan 1997 03:10:09.78 | 696.816        |

|    |                        |                        |         |
|----|------------------------|------------------------|---------|
| 39 | 5 Jan 1997 04:42:31.60 | 5 Jan 1997 04:50:13.32 | 461.721 |
| 40 | 5 Jan 1997 09:55:20.85 | 5 Jan 1997 10:05:44.07 | 623.212 |
| 41 | 5 Jan 1997 11:35:45.85 | 5 Jan 1997 11:47:46.47 | 720.622 |
| 42 | 5 Jan 1997 13:16:39.53 | 5 Jan 1997 13:28:23.72 | 704.194 |
| 43 | 5 Jan 1997 14:58:17.40 | 5 Jan 1997 15:07:30.36 | 552.956 |
| 44 | 5 Jan 1997 23:04:31.75 | 5 Jan 1997 23:14:04.49 | 572.740 |
| 45 | 6 Jan 1997 00:43:45.78 | 6 Jan 1997 00:55:36.03 | 710.248 |
| 46 | 6 Jan 1997 02:24:30.72 | 6 Jan 1997 02:36:27.44 | 716.721 |
| 47 | 6 Jan 1997 04:06:39.38 | 6 Jan 1997 04:16:48.86 | 609.478 |
| 48 | 6 Jan 1997 09:21:52.99 | 6 Jan 1997 09:30:21.73 | 508.739 |
| 49 | 6 Jan 1997 11:02:02.84 | 6 Jan 1997 11:13:46.32 | 703.485 |
| 50 | 6 Jan 1997 12:42:48.76 | 6 Jan 1997 12:54:50.24 | 721.482 |
| 51 | 6 Jan 1997 14:24:07.76 | 6 Jan 1997 14:34:23.14 | 615.376 |
| 52 | 6 Jan 1997 22:31:29.46 | 6 Jan 1997 22:39:43.72 | 494.262 |
| 53 | 7 Jan 1997 00:10:18.08 | 7 Jan 1997 00:21:43.04 | 684.965 |
| 54 | 7 Jan 1997 01:50:35.97 | 7 Jan 1997 02:02:42.84 | 726.875 |
| 55 | 7 Jan 1997 03:32:21.85 | 7 Jan 1997 03:43:15.27 | 653.420 |
| 56 | 7 Jan 1997 05:20:45.52 | 7 Jan 1997 05:21:24.51 | 38.990  |
| 57 | 7 Jan 1997 08:48:43.88 | 7 Jan 1997 08:54:00.72 | 316.843 |
| 58 | 7 Jan 1997 10:28:22.37 | 7 Jan 1997 10:39:39.03 | 676.660 |
| 59 | 7 Jan 1997 12:09:00.54 | 7 Jan 1997 12:21:08.67 | 728.123 |
| 60 | 7 Jan 1997 13:50:06.91 | 7 Jan 1997 14:01:08.52 | 661.619 |
| 61 | 7 Jan 1997 15:32:40.51 | 7 Jan 1997 15:38:50.29 | 369.780 |
| 62 | 7 Jan 1997 22:00:15.89 | 7 Jan 1997 22:04:41.11 | 265.222 |
| 63 | 7 Jan 1997 23:36:58.33 | 7 Jan 1997 23:47:45.96 | 647.631 |
| 64 | 8 Jan 1997 01:16:49.07 | 8 Jan 1997 01:28:56.11 | 727.047 |
| 65 | 8 Jan 1997 02:58:10.19 | 8 Jan 1997 03:09:36.96 | 686.768 |
| 66 | 8 Jan 1997 04:42:58.36 | 8 Jan 1997 04:49:29.54 | 391.178 |
| 67 | 8 Jan 1997 09:54:45.39 | 8 Jan 1997 10:05:25.29 | 639.903 |
| 68 | 8 Jan 1997 11:35:14.54 | 8 Jan 1997 11:47:19.10 | 724.560 |
| 69 | 8 Jan 1997 13:16:11.37 | 8 Jan 1997 13:27:46.12 | 694.756 |
| 70 | 8 Jan 1997 14:57:59.36 | 8 Jan 1997 15:06:43.13 | 523.767 |
| 71 | 8 Jan 1997 23:03:46.25 | 8 Jan 1997 23:13:42.68 | 596.428 |
| 72 | 9 Jan 1997 00:43:10.21 | 9 Jan 1997 00:55:07.09 | 716.882 |
| 73 | 9 Jan 1997 02:24:05.24 | 9 Jan 1997 02:35:55.57 | 710.332 |
| 74 | 9 Jan 1997 04:06:52.61 | 9 Jan 1997 04:16:11.45 | 558.841 |
| 75 | 9 Jan 1997 09:21:14.13 | 9 Jan 1997 09:30:38.84 | 564.715 |
| 76 | 9 Jan 1997 11:01:30.67 | 9 Jan 1997 11:13:21.78 | 711.106 |
| 77 | 9 Jan 1997 12:42:19.47 | 9 Jan 1997 12:54:15.70 | 716.226 |
| 78 | 9 Jan 1997 14:23:44.62 | 9 Jan 1997 14:33:38.56 | 593.938 |
| 79 | 9 Jan 1997 22:30:41.39 | 9 Jan 1997 22:39:28.58 | 527.184 |

Global Statistics

-----

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| Min Duration   | 56 | 7 Jan 1997 05:20:45.52 | 7 Jan 1997 05:21:24.51 | 38.990  |
| Max Duration   | 28 | 4 Jan 1997 01:51:05.45 | 4 Jan 1997 02:03:13.58 | 728.130 |
| Mean Duration  |    |                        | 600.532                |         |
| Total Duration |    |                        | 47442.048              |         |

Global Statistics

Latitude 55 degrees Elevation 20 degrees  
 11 Apr 1998 14:09:26  
 Chain-Sat\_ground\_lat55: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| 1      | 1 Jan 1997 00:12:10.09 | 1 Jan 1997 00:22:36.64 | 626.555        |
| 2      | 1 Jan 1997 01:52:17.00 | 1 Jan 1997 02:03:44.01 | 687.011        |
| 3      | 1 Jan 1997 03:33:24.15 | 1 Jan 1997 03:44:22.93 | 658.783        |
| 4      | 1 Jan 1997 05:18:27.12 | 1 Jan 1997 05:24:05.90 | 338.775        |
| 5      | 1 Jan 1997 10:29:30.31 | 1 Jan 1997 10:40:08.64 | 638.336        |
| 6      | 1 Jan 1997 12:10:01.86 | 1 Jan 1997 12:21:29.64 | 687.779        |
| 7      | 1 Jan 1997 13:51:00.83 | 1 Jan 1997 14:01:51.97 | 651.146        |
| 8      | 1 Jan 1997 15:32:56.75 | 1 Jan 1997 15:41:15.30 | 498.545        |
| 9      | 1 Jan 1997 23:38:47.46 | 1 Jan 1997 23:48:35.16 | 587.703        |
| 10     | 2 Jan 1997 01:18:36.53 | 2 Jan 1997 01:29:55.58 | 679.055        |
| 11     | 2 Jan 1997 02:59:26.40 | 2 Jan 1997 03:10:42.21 | 675.812        |
| 12     | 2 Jan 1997 04:42:10.77 | 2 Jan 1997 04:50:53.84 | 523.069        |
| 13     | 2 Jan 1997 09:55:57.31 | 2 Jan 1997 10:05:54.89 | 597.580        |
| 14     | 2 Jan 1997 11:36:17.47 | 2 Jan 1997 11:47:39.34 | 681.872        |
| 15     | 2 Jan 1997 13:17:08.15 | 2 Jan 1997 13:28:19.78 | 671.630        |
| 16     | 2 Jan 1997 14:58:37.83 | 2 Jan 1997 15:07:59.67 | 561.844        |
| 17     | 2 Jan 1997 23:05:29.53 | 2 Jan 1997 23:14:24.40 | 534.864        |
| 18     | 3 Jan 1997 00:45:01.48 | 3 Jan 1997 00:56:04.55 | 663.068        |
| 19     | 3 Jan 1997 02:25:33.42 | 3 Jan 1997 02:36:58.98 | 685.561        |
| 20     | 3 Jan 1997 04:07:02.56 | 3 Jan 1997 04:17:25.05 | 622.493        |
| 21     | 3 Jan 1997 09:22:34.18 | 3 Jan 1997 09:29:59.58 | 445.404        |
| 22     | 3 Jan 1997 11:02:35.36 | 3 Jan 1997 11:13:44.07 | 668.712        |
| 23     | 3 Jan 1997 12:43:18.41 | 3 Jan 1997 12:54:42.18 | 683.771        |
| 24     | 3 Jan 1997 14:24:32.12 | 3 Jan 1997 14:34:39.58 | 607.465        |
| 25     | 3 Jan 1997 16:08:33.40 | 3 Jan 1997 16:10:27.53 | 114.127        |
| 26     | 3 Jan 1997 22:32:36.00 | 3 Jan 1997 22:39:54.03 | 438.037        |
| 27     | 4 Jan 1997 00:11:31.80 | 4 Jan 1997 00:22:10.17 | 638.379        |
| 28     | 4 Jan 1997 01:51:45.56 | 4 Jan 1997 02:03:13.58 | 688.019        |
| 29     | 4 Jan 1997 03:32:58.99 | 4 Jan 1997 03:43:49.38 | 650.386        |
| 30     | 4 Jan 1997 05:19:10.92 | 4 Jan 1997 05:23:09.37 | 238.451        |
| 31     | 4 Jan 1997 08:49:44.65 | 4 Jan 1997 08:53:12.07 | 207.418        |
| 32     | 4 Jan 1997 10:28:56.06 | 4 Jan 1997 10:39:44.21 | 648.157        |
| 33     | 4 Jan 1997 12:09:31.05 | 4 Jan 1997 12:20:59.15 | 688.102        |
| 34     | 4 Jan 1997 13:50:33.55 | 4 Jan 1997 14:01:14.61 | 641.059        |
| 35     | 4 Jan 1997 15:32:45.04 | 4 Jan 1997 15:40:22.74 | 457.703        |
| 36     | 4 Jan 1997 23:38:07.29 | 4 Jan 1997 23:48:11.08 | 603.793        |
| 37     | 5 Jan 1997 01:18:03.04 | 5 Jan 1997 01:29:26.02 | 682.981        |
| 38     | 5 Jan 1997 02:58:59.54 | 5 Jan 1997 03:10:09.78 | 670.237        |

|    |                        |                        |         |
|----|------------------------|------------------------|---------|
| 39 | 5 Jan 1997 04:42:31.60 | 5 Jan 1997 04:50:13.32 | 461.721 |
| 40 | 5 Jan 1997 09:55:20.85 | 5 Jan 1997 10:05:40.30 | 619.443 |
| 41 | 5 Jan 1997 11:35:45.85 | 5 Jan 1997 11:47:10.81 | 684.962 |
| 42 | 5 Jan 1997 13:16:39.53 | 5 Jan 1997 13:27:44.43 | 664.903 |
| 43 | 5 Jan 1997 14:58:17.40 | 5 Jan 1997 15:07:17.92 | 540.517 |
| 44 | 5 Jan 1997 23:04:47.63 | 5 Jan 1997 23:14:04.49 | 556.860 |
| 45 | 6 Jan 1997 00:44:25.94 | 6 Jan 1997 00:55:36.03 | 670.093 |
| 46 | 6 Jan 1997 02:25:04.71 | 6 Jan 1997 02:36:27.44 | 682.725 |
| 47 | 6 Jan 1997 04:06:39.38 | 6 Jan 1997 04:16:48.86 | 609.476 |
| 48 | 6 Jan 1997 09:21:52.99 | 6 Jan 1997 09:30:21.73 | 508.739 |
| 49 | 6 Jan 1997 11:02:02.84 | 6 Jan 1997 11:13:17.38 | 674.542 |
| 50 | 6 Jan 1997 12:42:48.76 | 6 Jan 1997 12:54:08.88 | 680.122 |
| 51 | 6 Jan 1997 14:24:07.76 | 6 Jan 1997 14:33:59.58 | 591.816 |
| 52 | 6 Jan 1997 22:31:32.39 | 6 Jan 1997 22:39:43.72 | 491.331 |
| 53 | 7 Jan 1997 00:10:54.24 | 7 Jan 1997 00:21:43.04 | 648.798 |
| 54 | 7 Jan 1997 01:51:14.89 | 7 Jan 1997 02:02:42.84 | 687.956 |
| 55 | 7 Jan 1997 03:32:34.42 | 7 Jan 1997 03:43:15.27 | 640.854 |
| 56 | 7 Jan 1997 05:20:45.52 | 7 Jan 1997 05:21:24.51 | 38.990  |
| 57 | 7 Jan 1997 08:48:43.88 | 7 Jan 1997 08:54:00.72 | 316.843 |
| 58 | 7 Jan 1997 10:28:22.37 | 7 Jan 1997 10:39:19.20 | 656.827 |
| 59 | 7 Jan 1997 12:09:00.54 | 7 Jan 1997 12:20:27.90 | 687.358 |
| 60 | 7 Jan 1997 13:50:06.91 | 7 Jan 1997 14:00:36.49 | 629.588 |
| 61 | 7 Jan 1997 15:32:40.51 | 7 Jan 1997 15:38:50.29 | 369.780 |
| 62 | 7 Jan 1997 22:00:15.89 | 7 Jan 1997 22:04:41.11 | 265.222 |
| 63 | 7 Jan 1997 23:37:27.81 | 7 Jan 1997 23:47:45.96 | 618.149 |
| 64 | 8 Jan 1997 01:17:30.33 | 8 Jan 1997 01:28:56.11 | 685.786 |
| 65 | 8 Jan 1997 02:58:33.35 | 8 Jan 1997 03:09:36.96 | 663.615 |
| 66 | 8 Jan 1997 04:42:58.36 | 8 Jan 1997 04:49:29.54 | 391.178 |
| 67 | 8 Jan 1997 09:54:45.39 | 8 Jan 1997 10:05:16.75 | 631.360 |
| 68 | 8 Jan 1997 11:35:14.54 | 8 Jan 1997 11:46:41.55 | 687.012 |
| 69 | 8 Jan 1997 13:16:11.37 | 8 Jan 1997 13:27:08.31 | 656.946 |
| 70 | 8 Jan 1997 14:57:59.36 | 8 Jan 1997 15:06:35.56 | 516.203 |
| 71 | 8 Jan 1997 23:04:06.36 | 8 Jan 1997 23:13:42.68 | 576.316 |
| 72 | 9 Jan 1997 00:43:51.17 | 9 Jan 1997 00:55:07.09 | 675.919 |
| 73 | 9 Jan 1997 02:24:36.72 | 9 Jan 1997 02:35:55.57 | 678.855 |
| 74 | 9 Jan 1997 04:06:52.61 | 9 Jan 1997 04:16:11.45 | 558.841 |
| 75 | 9 Jan 1997 09:21:14.13 | 9 Jan 1997 09:30:38.84 | 564.715 |
| 76 | 9 Jan 1997 11:01:30.67 | 9 Jan 1997 11:12:50.01 | 679.333 |
| 77 | 9 Jan 1997 12:42:19.47 | 9 Jan 1997 12:53:34.81 | 675.333 |
| 78 | 9 Jan 1997 14:23:44.62 | 9 Jan 1997 14:33:18.89 | 574.276 |
| 79 | 9 Jan 1997 22:30:49.51 | 9 Jan 1997 22:39:28.58 | 519.063 |

# Global Statistics

|                |    |                        |                        |         |
|----------------|----|------------------------|------------------------|---------|
| Min Duration   | 56 | 7 Jan 1997 05:20:45.52 | 7 Jan 1997 05:21:24.51 | 38.990  |
| Max Duration   | 33 | 4 Jan 1997 12:09:31.05 | 4 Jan 1997 12:20:59.15 | 688.102 |
| Mean Duration  |    |                        | 579.444                |         |
| Total Duration |    |                        | 45776.048              |         |

## Appendix 2

11 Apr 1998 16:20:31

Chain-Chain1: Complete Chain Access

| Access | Start Time (UTCG)      | Stop Time (UTCG)       | Duration (sec) |
|--------|------------------------|------------------------|----------------|
| 1      | 1 Jan 1997 00:04:55.51 | 1 Jan 1997 00:25:06.78 | 1211.274       |



## Appendix 3

```

/*pre-processor library links*/
#include <stdio.h>
#include <math.h>
#include <values.h>
#include <iostream.h>
/*various user defined structures */
struct adj_matrix
{
    int A[66][66];
};

struct sat_info /*if tag=0 then satellite has not been reached by a g_s*/
{
    int tag; /* if tag=1 then satellite has been reached by a ground satition*/
    float lon; /*longitude of sub-satellite point at initial geometry, time 0*/
    float lat; /*latitude of sub-satellite point at initial geometry, time 0*/
};

struct all_sats
{
    sat_info x[66];
};

struct gstations_info
{
    int z; /* number of ground stations needed*/
    float lat[66]; /*latitude of each ground station*/
    float lon[66]; /*longitude of each groudnn station*/
    int check;
};

/*funciton headers */
adj_matrix Adj_matrix(int,int);
adj_matrix Adj_matrix_mid(int,int);
FILE* fopener(void);
int get_sat(int,int,all_sats);
int shortest_path(adj_matrix, int , int );
gstations_info how_many_gs(float,float,all_sats,int,int,int,int);
int test_gs(gstations_info,float,float,all_sats, int , int ,int ,int);

/*Global Variables*/
FILE *latp;
FILE *lonp;
FILE *testp;
adj_matrix pre_ep,post_ep,mid_ep;

```

```

main()
{ int planes,sats_per_plane,i,gpt,clpt,spt,count,p,p2,check;
  float epsilon,mean_tiv;
  all_sats iridium;
  gstations_info optimal,constrained;

  cout<<"open test file"<<endl;
  testp=fopener();
  /*Declare variables for the iridium system*/
  clpt=2; /*command load processing time at ground station*/
  spt=1; /*satellite processing time*/
  gpt=5; /*ground station health and safety data processing time*/
  planes=6;
  sats_per_plane=11;
  epsilon=207.0; /*time before intial geometry changes*/
  mean_tiv=572.7903333; /*mean time in view */

  /*compute the adjancey matrices before and after epsilon*/
  cout<<"Enter data on pre_epsilon crosslinks"<<endl;
  pre_ep=Adj_matrix(planes,sats_per_plane);
  cout<<"Enter data on post_epsilon crosslinks"<<endl;
  post_ep=Adj_matrix(planes,sats_per_plane);
  cout<<"Enter data on transitional crosslinks"<<endl;
  mid_ep=Adj_matrix_mid(planes,sats_per_plane);
  /* set the tags for the iridium structures equal to all zero indicating
  that the satellite has yet to be commanded by a ground station*/
  /* initialize the longitude and latitude for the satellites to their
  sub-satellite point longitude and latitude at initial geometry, ie time
  zero*/
  cout<<endl;
  cout<<"Enter the name of the file which has sat's latitude info"<<endl;
  latp=fopener();
  cout<<endl;
  cout<<"Enter the name of the file which has sat's longitude info"<<endl;
  lonp=fopener();
  cout<<endl;
  for(i=0;i<=65;i++)
  { iridium.x[i].tag=0;
    fscanf(latp,"%f",&iridium.x[i].lat);
    fscanf(lonp,"%f",&iridium.x[i].lon);
  }

  /*call how_many_gs to determine the optimal number without regard to land or
  political constraints*/
  /*      for(p=1;p<=82;p=p+9) /*p is the range of delay times*/

```

```

/*      {cout<<"for this run p="<<p<<endl;
          optimal=how_many_gs(mean_tiv,epsilon,iridium,p,gpt,clpt,spt);
          if(optimal.z>=65)
              p=MAXINT;
          } */
/*use test_gs to test different ground stations with a given value of p to
adjust the optimal set to account for land and political constraints*/
/*Note that you must set up the gstations_info, constrained, each time you
want to check a new set of ground stations, you must also modify p2*/
p2=1;
constrained.z=55;
constrained.lat[0]=40; constrained.lon[0]=-80;
constrained.lat[1]=-15; constrained.lon[1]=-40;
check=test_gs(constrained,mean_tiv,epsilon,iridium,p2,gpt,clpt,spt);
cout<<"check="<<check<<endl;
return(0);
}

/* The subroutine how_many_gs is the main subroutine. It is basically a giant
loop that given a value of p, the delay time on a satellite, computes the
number of ground stations that will be required to command Iridium within one
satellite pass. It takes several pieces of information which are:
double Mean time in view, double epsilon- the time at which geometry changes,
two adjancey matrices one for pre-epsilon time and one for post-epsilon time,
an all_sats which contains the longitude and latitude and the tag for all of
the satellites at the begining of the pass, p the satellite delay time, and x
the processing time on the ground. It returns a data structure of the type
g_stations_info which has the number of ground stations required for a given p
value and the longitude and latitude of each of those ground stations. The
subroutine works by searching through each longitude and latitude position
(with 5 degree increments, although this could be altered to any desired
increment by changing the for loop, and determing how many satellites that site
will be able to command, picking the one that commands the most, then running
the loop again until all satellites have been commanded*/
gstations_info how_many_gs(float tiv,float ep, all_sats z, int p, int gpt,int clpt,int spt)
/*start how_many_gs-----*/
{ all_sats temp_sats, mid_sats;
  int gs_count, watch, root_sat,sats_covered, max_sats, i,j,k, alpha,beta;
  int m;
  float request,respond,delay;
  gstations_info ansr;

  temp_sats=z; gs_count=0;
  do
  { max_sats=0;

```

```

for(i=65;i>=-65;i=i-5) /*latitude incrementor*/
{ for(j=180;j>=-175;j=j-5) /*longitude incrementor*/
{
    for(m=0;m<=65;m++)
        temp_sats.x[m].tag=0;
    root_sat=get_sat(i,j,z); /*find the sat closest to this lat/lon*/
    temp_sats.x[root_sat].tag=1;
    sats_covered=1;
    for(k=0;k<=65;k++)
        { if(z.x[k].tag==0 && k!=root_sat)
            { alpha=shortest_path(pre_ep,root_sat,k);
              request=(alpha*p);
              if(request>ep/2.0)
                  alpha=shortest_path(mid_ep,root_sat,k);
              request=(alpha+1)*p+spt;
              if(request<=(ep/2.0))
                  beta=alpha;
              if(request>(ep/2.0) && request<ep)
                  beta=shortest_path(mid_ep,k,root_sat);
              if(request>=ep)
                  beta=shortest_path(post_ep,k,root_sat);
              respond=(beta+1)*p;
              delay=respond+request+gpt+clpt;
              if(delay<tiv)
                  { temp_sats.x[k].tag=1;
                    sats_covered=sats_covered+1;
                  }
            }
        } /*closes first if*/
    } /*closes k loop */
    if(sats_covered>max_sats)
        { max_sats=sats_covered;
          ansr.lon[gs_count]=j;
          ansr.lat[gs_count]=i;
          mid_sats=temp_sats;
        }
    } /*closes j*/
} /*closes i*/
for(m=0;m<=65;m++)
{ if(mid_sats.x[m].tag==1)
    z.x[m].tag=1;}
for(m=0;m<=65;m++)
{ if(z.x[m].tag==1)
    watch=0;
  }
}
for(m=0;m<=65;m++)

```

```

        {if(z.x[m].tag==0)
            watch=1;
        }
        gs_count=gs_count+1;
        cout<<"gscount="<<gs_count<<endl;
        cout<<"ansr.lon="<<ansr.lon[gs_count-1]<<"--ansr.lat="<<ansr.lat[gs_count-1]<<endl;
    } while(watch==1 && gs_count<=66 );
    ansr.z=gs_count; ansr.check=watch;
    fprintf(testp,"\n For p=%d, the number of ground stations was %d",p,gs_count);
    for(m=0;m<=(gs_count-1);m++)
        fprintf(testp,"\n Lat=%f \t Lon=%f \n",ansr.lat[m],ansr.lon[m]);
    return(ansr);
}/*end how_many_gs*/

```

/\*The test\_gs is used to test a set of ground stations to see if they will satisfy the commanding requirements. When called the function takes a data structure of the type gstations\_info, the mean time in view, epsilon, gpt,clpt, spt,p delay time, and an all sats. It returns an integer, check. If check equals 0 then the given set of ground station coordinates will successfully command all of the ground stations. If check equals 1 then the given set fails.\*/

```

int test_gs(gstations_info x,float tiv,float ep,all_sats z,int p,int gpt,int clpt,int spt)
/*start how_many_gs-----*/
{
    int root_sat, i,j,k, alpha,beta;
    int m,check,count;
    float request,respond,delay;

```

```

    for(count=0;count<=x.z-1;count++)
    { i=x.lat[count]; j=x.lon[count];
      root_sat=get_sat(i,j,z); /*find the sat closest to this lat/lon*/
      z.x[root_sat].tag=1;
      for(k=0;k<=65;k++)
          { if(z.x[k].tag==0 && k!=root_sat)
              { alpha=shortest_path(pre_ep,root_sat,k);
                request=(alpha*p);
                if(request>ep/2.0)
                    alpha=shortest_path(mid_ep,root_sat,k);
                request=(alpha+1)*p+spt;
                if(request<=(ep/2.0))
                    beta=alpha;
                if(request>(ep/2.0) && request<ep)
                    beta=shortest_path(mid_ep,k,root_sat);
                if(request>=ep)
                    beta=shortest_path(post_ep,k,root_sat);

```

```

        respond=(beta+1)*p;
        delay=respond+request+gpt+clpt;
        if(delay<tiv)
            {z.x[k].tag=1;
             }
        }/*closes first if*/
    }/*closes k loop */
}/*closes first for loop,count*/

check=0;
for(m=0;m<=65;m++)
    {if(z.x[m].tag==0)
        check=1;
    }
return(check);
}/*end how_many_gs*/

/*The shortest_path subroutine is used to find the shortest path between
satellites A and B. It is dependent on the adjancey matrix that is used
when the function is called. The adjancey matrix is dependent on the
current satellite geometry, that is on the cross links*/
int shortest_path(adj_matrix A, int b, int final)
{ int v1[66],v2[66],v3[66],count,max,min_path,c2,root;
  int i,wi,wj,j,k,m,max_wt,bell,wt,ansr,no_path,x;
  int e2[264][2];
  max=67; /*set max equal number of satellites plus 1*/
  /*initialize*/
  i=b;
  wi=0;
  wj=0;
  count=0;
  for(j=0;j<=1;j++)
      { for(k=0;k<=263;k++)
          {
              e2[k][j]=max;
          }
      }
  for(j=0;j<=65;j++)
      { if(j==b)
          { v3[j]=max;
            v2[j]=max;
            v1[j]=b;
          }
        else
          { v3[j]=j;

```

```

        v2[j]=max;
        v1[j]=max;
    }
}

do
{ for(j=0;j<=65;j++)
    { if(A.A[i][j]==1)
        {
            wj=1;
            if(v2[j]!=max)
                { root=v2[j]; min_path=0;
                  for(c2=0;c2<=263;c2++)
                      {
                          if(e2[c2][0]==b && e2[c2][1]==root)
                              { min_path=min_path+1;
                                c2=265;
                              }
                          if(e2[c2][0]!=b && e2[c2][1]==root)
                              { root=e2[c2][0];
                                min_path=min_path+1;
                                c2=-1;
                              }
                      }
                          } /*remove the edge from e2 */
            if((wi+wj)<min_path)
                { for(c2=0;c2<=263;c2++)
                    { if(e2[c2][1]==j)
                        { e2[c2][0]=max;
                          e2[c2][1]=max;
                        }
                    }
                }

            m=0;
            do /*add the edge to e2*/
                { if(e2[m][0]==max && e2[m][1]==max)
                    { e2[m][0]=i;
                      e2[m][1]=j;
                      m=MAXINT;
                    }
                else
                    m=m+1;
            } while(m != MAXINT);
        }
    }
    if(v3[j]!=max)

```



```

        {v3[j]=max;
         v2[j]=j;
         k=0;
         do
             {if(e2[k][0]==max && e2[k][1]==max)
                 {e2[k][0]=i;
                  e2[k][1]=j;
                  k=MAXINT;
                 }
              else
                 k=k+1;
             }while(k !=MAXINT );
        }
    }

    no_path=0;
    for(k=0;k<=65;k++)
        {if(v2[k]!=max)
            no_path=1;
        }
    if(no_path==0)
        {cout<<"NO PATH FOR THESE SATELLITES"<<endl;
         return(MAXINT);
        }

    max_wt=MAXINT;
    for(bell=0;bell<=65;bell++)
        {if(v2[bell]!=max)
            {root=v2[bell]; wt=0;
             for(c2=0;c2<=263;c2++)
                 {if(e2[c2][0]==b && e2[c2][1]==root)
                     {wt=wt+1;
                      c2=265;
                     }
                  if(e2[c2][0]!=b && e2[c2][1]==root)
                     {root=e2[c2][0];
                      wt=wt+1;
                      c2=-1;
                     }
                 }
             if(wt<max_wt)
                 {max_wt=wt;
                  x=v2[bell];
                 }
            }
        }

```

```

    }

    v2[x]=max;
    v1[x]=x;
    i=x;
    wi=max_wt;
    count=count+1;
}while(i!=final && count<1000);

ansr=max_wt;
return(ansr);
}/*end shortest_path*/

```

/\* The get\_sat subroutine is used to find the root satellite for a given ground station latitude and longitude position. It is based on the initial geometry of the system. It will compare the ground station latitude and longitude to the latitude and longitude of every satellite, finding the one that is closest to the ground station coordinates and therefore the one that a ground station at those coordinates would be in contact with. It takes two integers i and j which are the latitude and longitude respectively of the ground station. It returns an integer which is the index number of the iridium satellite that is closest of those coordinates\*/

```

int get_sat(int lat, int lon, all_sats z)
{ int i, ansr;
  float sat_lat, sat_lon, t1, t2, td, total_dif;

  t1=0; t2=0; td=0; total_dif=1000;
  for(i=0; i<=65; i++)
  { sat_lat=z.x[i].lat;
    sat_lon=z.x[i].lon;
    if(fabs(lon)>=30.0 && fabs(lon)<=150 && fabs(lat)>=17)
    {if(lon<=0.0 && lat>=0 && sat_lat>=0 && sat_lon<=0)
      {t1=fabs(lon)-fabs(sat_lon);
        t1=fabs(t1);
        t2=fabs(lat-sat_lat);
        td=t1+t2;
        if(td<total_dif)
        {total_dif=td;
          ansr=i;
        }
      }
    }
    if(lon>=0 && lat>=0 && sat_lat>=0 && sat_lon>=0)
    {t1=fabs(lon-sat_lon);
      t2=fabs(lat-sat_lat);

```

```

        td=t1+t2;
        if(td<total_dif)
            {total_dif=td;
            ansr=i;
            }
        }
    if(lon>=0 && lat<=0 && sat_lon>=0 && sat_lat<=0)
        {t1=fabs(lon-sat_lon);
        t2=fabs(lat)-fabs(sat_lat);
        t2=fabs(t2);
        td=t1+t2;
        if(td<total_dif)
            {total_dif=td;
            ansr=i;
            }
        }
    if(lon<=0 && lat<=0 && sat_lon<=0 && sat_lat<=0)
        {t1=fabs(lon)-fabs(sat_lon);
        t1=fabs(t1);
        t2=fabs(lat)-fabs(sat_lat);
        t2=fabs(t2);
        td=t1+t2;
        if(td<total_dif)
            {total_dif=td;
            ansr=i;
            }
        }
    }
    if(lat>=17)
        {if(lon>=150 && sat_lon>=120 && sat_lat>=0)
            {t1=fabs(lon-sat_lon);
            t2=fabs(lat-sat_lat);
            td=t1+t2;
            if(td<total_dif)
                {total_dif=td;
                ansr=i;
                }
            }
        }
    if(lon>=150 && sat_lon<=-150 && sat_lat>=0)
        {t1=(180-lon)+(180-fabs(sat_lon));
        t2=fabs(lat-sat_lat);
        td=t1+t2;
        if(td<total_dif)
            {total_dif=td;
            ansr=i;
            }
        }

```

```

        }
    }
    if(lon<=-150 && sat_lon<=-120 && sat_lat>=0)
    {t1=fabs(lon)-fabs(sat_lon);
      t1=fabs(t1);
      t2=fabs(lat-sat_lat);
      td=t1+t2;
      if(td<total_dif)
      {total_dif=td;
        ansr=i;
      }
    }
    if(lon<=-150 && sat_lon>=150 && sat_lat>=0)
    {t1=(180-sat_lon)+(180-fabs(lon));
      t2=fabs(sat_lat-lat);
      td=t1+t2;
      if(td<total_dif)
      {total_dif=td;
        ansr=i;
      }
    }
  }
  if(lat<=-17)
  {if(lon>=150 && sat_lon>=120 && sat_lat<=0)
    {t1=fabs(lon-sat_lon);
      t2=fabs(lat)-fabs(sat_lat);
      t2=fabs(t2);
      td=t1+t2;
      if(td<total_dif)
      {total_dif=td;
        ansr=i;
      }
    }
    if(lon>=150 && sat_lon<=-150 && sat_lat<=0)
    {t1=(180-lon)+(180-fabs(sat_lon));
      t2=fabs(lat)-fabs(sat_lat);
      t2=fabs(t2);
      td=t1+t2;
      if(td<total_dif)
      {total_dif=td;
        ansr=i;
      }
    }
  }
  if(lon<=-150 && sat_lon<=-120 && sat_lat<=0)
  {t1=fabs(lon)-fabs(sat_lon);

```

```

        t1=fabs(t1);
        t2=fabs(lat)-fabs(sat_lat);
        t2=fabs(t2);
        td=t1+t2;
        if(td<total_dif)
            { total_dif=td;
              ansr=i;
            }
    }
    if(lon<=-150 && sat_lon>=150 && sat_lat<=0)
        { t1=(180-sat_lon)+(180-fabs(lon));
          t2=fabs(lat)-fabs(sat_lat);
          t2=fabs(t2);
          td=t1+t2;
          if(td<total_dif)
              { total_dif=td;
                ansr=i;
              }
        }
    }
    if(lat>=17 && fabs(lon)<=30 && fabs(sat_lon)<=60 && sat_lat>=0)
        { if(lon>=0 && sat_lon>=0)
            { t1=fabs(lon-sat_lon);
              t2=fabs(lat-sat_lat);
              td=t1+t2;
              if(td<total_dif)
                  { total_dif=td;
                    ansr=i;
                  }
            }
        }
    if(lon>=0 && sat_lon<=0)
        { t1=lon+fabs(sat_lon);
          t2=fabs(sat_lat-lat);
          td=t1+t2;
          if(td<total_dif)
              { total_dif=td;
                ansr=i;
              }
        }
    }
    if(lon<=0 && sat_lon>=0)
        { t1=fabs(lon) + sat_lon;
          t2=fabs(sat_lat-lat);
          td=t1+t2;
          if(td<total_dif)
              { total_dif=td;

```

```

        ansr=i;
    }
}
if(lon<=0 && sat_lon<=0)
{t1=fabs(lon)-fabs(sat_lon);
t1=fabs(t1);
t2=fabs(sat_lat-lat);
td=t1+t2;
if(td<total_dif)
{total_dif=td;
ansr=i;
}
}
}

if(lat<=-17 && fabs(lon)<=30 && fabs(sat_lon)<=60 && sat_lat<=0)
{if(lon>=0 && sat_lon>=0)
{t1=fabs(lon-sat_lon);
t2=fabs(sat_lat)-fabs(lat);
t2=fabs(t2);
td=t1+t2;
if(td<total_dif)
{total_dif=td;
ansr=i;
}
}
if(lon>=0 && sat_lon<=0)
{t1=lon+fabs(sat_lon);
t2=fabs(sat_lat)-fabs(lat);
t2=fabs(t2);
td=t1+t2;
if(td<total_dif)
{total_dif=td;
ansr=i;
}
}
if(lon<=0 && sat_lon>=0)
{t1=fabs(lon) + sat_lon;
t2=fabs(sat_lat)-fabs(lat);
t2=fabs(t2);
td=t1+t2;
if(td<total_dif)
{total_dif=td;
ansr=i;
}
}
}

```

```

    }
    if(lon<=0 && sat_lon<=0)
    {
        t1=fabs(lon)-fabs(sat_lon);
        t1=fabs(t1);
        t2=fabs(sat_lat)-fabs(lat);
        t2=fabs(t2);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
}

if(fabs(lat)<=17)
{
    if(lat>=0)
    {
        if(lon>=30 && lon<=150 && sat_lon>=0)
        {
            if(sat_lat<=0)
            {
                t1=fabs(sat_lat)+lat;
                t2=fabs(lon-sat_lon);
                td=t1+t2;
                if(td<total_dif)
                {
                    total_dif=td;
                    ansr=i;
                }
            }
            if(sat_lat>=0)
            {
                t1=fabs(sat_lat-lat);
                t2=fabs(lon-sat_lon);
                td=t1+t2;
                if(td<total_dif)
                {
                    total_dif=td;
                    ansr=i;
                }
            }
        }
    }
    if(lon<=-30 && lon>=-150 && sat_lon<=0)
    {
        if(sat_lat<0)
        {
            t1=fabs(sat_lat)+lat;
            t2=fabs(sat_lon)-fabs(lon);
            t2=fabs(t2);
            td=t1+t2;
            if(td<total_dif)
            {
                total_dif=td;
                ansr=i;
            }
        }
    }
}

```

```

        }
    }
    if(sat_lat>=0)
    {
        t1=fabs(lat-sat_lat);
        t2=fabs(sat_lon)-fabs(lon);
        t2=fabs(t2);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
}
if(lon>=0 && lon<=30)
{
    if(sat_lat>=0 && sat_lon>=0)
    {
        t1=fabs(lat-sat_lat);
        t2=fabs(lon-sat_lon);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat>=0 && sat_lon<=0)
    {
        t1=fabs(sat_lat-lat);
        t2=lon+fabs(sat_lon);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat<=0 && sat_lon>=0)
    {
        t1=lat+fabs(sat_lat);
        t2=fabs(sat_lon-lon);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat<=0 && sat_lon<=0)
    {
        t1=lat+fabs(sat_lat);
        t2=lon+fabs(sat_lon);
        td=t1+t2;
    }
}

```



```

        if(td<total_dif)
            {total_dif=td;
             ansr=i;
            }
        }
    }
if(lon<=0 && lon>=-30)
{ if(sat_lat>=0 && sat_lon>=0)
    {t1=fabs(lat-sat_lat);
     t2=fabs(lon)+sat_lon;
     td=t1+t2;
     if(td<total_dif)
         {total_dif=td;
          ansr=i;
         }
    }
if(sat_lat>=0 && sat_lon<=0)
    {t1=fabs(sat_lat-lat);
     t2=fabs(sat_lon)-fabs(lon);
     t2=fabs(t2);
     td=t1+t2;
     if(td<total_dif)
         {total_dif=td;
          ansr=i;
         }
    }
if(sat_lat<=0 && sat_lon>=0)
    {t1=lat+fabs(sat_lat);
     t2=fabs(lon)+sat_lon;
     td=t1+t2;
     if(td<total_dif)
         {total_dif=td;
          ansr=i;
         }
    }
if(sat_lat<=0 && sat_lon<=0)
    {t1=fabs(sat_lat)+lat;
     t2=fabs(lon)-fabs(sat_lon);
     t2=fabs(t2);
     td=t1+t2;
     if(td<total_dif)
         {total_dif=td;
          ansr=i;
         }
    }
}

```

```

    }
    if(lon>=150)
    {
        if(sat_lat>=0 && sat_lon>=0)
        {
            t1=fabs(lat-sat_lat);
            t2=fabs(lon-sat_lon);
            td=t1+t2;
            if(td<total_dif)
            {
                total_dif=td;
                ansr=i;
            }
        }
    }
    if(sat_lat>=0 && sat_lon<=-150)
    {
        t1=fabs(lat-sat_lat);
        t2=(180-lon)+(180-fabs(sat_lon));
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat<=0 && sat_lon>=0)
    {
        t1=fabs(lon-sat_lon);
        t2=fabs(sat_lat)+lat;
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat<=0 && sat_lon<=-150)
    {
        t1=fabs(sat_lat)+lat;
        t2=(180-lon)+(180-fabs(sat_lon));
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
}

if(lon<=-150)
{
    if(sat_lat>=0 && sat_lon<=0)
    {
        t1=fabs(lat-sat_lat);
        t2=fabs(lon)-fabs(sat_lon);
        t2=fabs(t2);
        td=t1+t2;
    }
}

```

```

        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat>=0 && sat_lon>=150)
    {
        t1=fabs(lat-sat_lat);
        t2=(180-sat_lon)+(180-fabs(lon));
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat<=0 && sat_lon<=0)
    {
        t2=fabs(lon)-fabs(sat_lon);
        t2=fabs(t2);
        t1=fabs(sat_lat)+lat;
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat<=0 && sat_lon>=150)
    {
        t1=fabs(sat_lat)+lat;
        t2=(180-sat_lon)+(180-fabs(lon));
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
}
if(lat<=0)
{
    if(lon>=30 && lon<=150 && sat_lon>=0)
    {
        if(sat_lat<=0)
        {
            t1=fabs(lat)-fabs(sat_lat);
            t1=fabs(t1);
            t2=fabs(lon-sat_lon);
            td=t1+t2;
            if(td<total_dif)
            {
                total_dif=td;
                ansr=i;
            }
        }
    }
}

```

```

        }
    }
    if(sat_lat>=0)
    {
        t1=fabs(lat)+sat_lat;
        t2=fabs(lon-sat_lon);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
}
if(lon<=-30 && lon>=-150 && sat_lon<=0)
{
    if(sat_lat<=0)
    {
        t1=fabs(sat_lat)-fabs(lat);
        t1=fabs(t1);
        t2=fabs(sat_lon)-fabs(lon);
        t2=fabs(t2);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
    if(sat_lat>=0)
    {
        t1=fabs(lat)+sat_lat;
        t2=fabs(sat_lon)-fabs(lon);
        t2=fabs(t2);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
}
if(lon>=0 && lon<=30)
{
    if(sat_lat>=0 && sat_lon>=0)
    {
        t1=fabs(lat)+sat_lat;
        t2=fabs(lon-sat_lon);
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
}

```

```

if(sat_lat>=0 && sat_lon<=0)
{
    t1=fabs(lat)+sat_lat;
    t2=lon+fabs(sat_lon);
    td=t1+t2;
    if(td<total_dif)
    {
        total_dif=td;
        ansr=i;
    }
}
if(sat_lat<=0 && sat_lon>=0)
{
    t1=fabs(sat_lat)-fabs(lat);
    t1=fabs(t1);
    t2=fabs(lon-sat_lon);
    td=t1+t2;
    if(td<total_dif)
    {
        total_dif=td;
        ansr=i;
    }
}
if(sat_lat<=0 && sat_lon<=0)
{
    t1=fabs(sat_lat)-fabs(lat);
    t1=fabs(t1);
    t2=fabs(sat_lon)+lon;
    td=t1+t2;
    if(td<total_dif)
    {
        total_dif=td;
        ansr=i;
    }
}
}
if(lon<=0 && lon>=-30)
{
    if(sat_lat>=0 && sat_lon>=0)
    {
        t1=fabs(lat)+sat_lat;
        t2=fabs(lon)+sat_lon;
        td=t1+t2;
        if(td<total_dif)
        {
            total_dif=td;
            ansr=i;
        }
    }
}
if(sat_lat>=0 && sat_lon<=0)
{
    t1=fabs(lat)+sat_lat;
    t2=fabs(lon)-fabs(sat_lon);
    t2=fabs(t2);
    td=t1+t2;

```

```

        if(td<total_dif)
            {total_dif=td;
             ansr=i;
            }
    }
    if(sat_lat<=0 && sat_lon>=0)
        {t1=fabs(lat)-fabs(sat_lat);
         t1=fabs(t1);
         t2=fabs(lon)+sat_lon;
         td=t1+t2;
         if(td<total_dif)
             {total_dif=td;
              ansr=i;
             }
        }
    if(sat_lat<=0 && sat_lon<=0)
        {t1=fabs(lat)-fabs(sat_lat);
         t1=fabs(t1);
         t2=fabs(lon)-fabs(sat_lon);
         t2=fabs(t2);
         td=t1+t2;
         if(td<total_dif)
             {total_dif=td;
              ansr=i;
             }
        }
    }
    if(lon>=150)
        {if(sat_lat>=0 && sat_lon>=0)
            {t1=fabs(lat)+sat_lat;
             t2=fabs(lon-sat_lon);
             td=t1+t2;
             if(td<total_dif)
                 {total_dif=td;
                  ansr=i;
                 }
            }
        }
    if(sat_lat>=0 && sat_lon<=-150)
        {t1=fabs(lat)+sat_lat;
         t2=(180-lon)+(180-fabs(sat_lon));
         td=t1+t2;
         if(td<total_dif)
             {total_dif=td;
              ansr=i;
             }
        }

```

```

    }
    if(sat_lat<=0 && sat_lon>=0)
    {t1=fabs(lat)-fabs(sat_lat);
    t1=fabs(t1);
    t2=fabs(lon-sat_lon);
    td=t1+t2;
    if(td<total_dif)
        {total_dif=td;
        ansr=i;
        }
    }
    if(sat_lat<=0 && sat_lon<=-150)
    {t1=fabs(lat)-fabs(sat_lat);
    t1=fabs(t1);
    t2=(180-lon)+(180-fabs(sat_lon));
    td=t1+t2;
    if(td<total_dif)
        {total_dif=td;
        ansr=i;
        }
    }
}
if(lon<=-150)
{if(sat_lat>=0 && sat_lon<=0)
    {t1=fabs(lat)+sat_lat;
    t2=fabs(lon)-fabs(sat_lon);
    t2=fabs(t2);
    td=t1+t2;
    if(td<total_dif)
        {total_dif=td;
        ansr=i;
        }
    }
    if(sat_lat>=0 && sat_lon>=150)
    {t1=fabs(lat)+sat_lat;
    t2=(180-sat_lon)+(180-fabs(lon));
    td=t1+t2;
    if(td<total_dif)
        {total_dif=td;
        ansr=i;
        }
    }
    if(sat_lat<=0 && sat_lon<=0)
    {t1=fabs(lat)-fabs(sat_lat);
    t1=fabs(t1);

```

```

        t2=fabs(lon)-fabs(sat_lon);
        t2=fabs(t2);
        td=t1+t2;
        if(td<total_dif)
            {total_dif=td;
             ansr=i;
            }
    }
    if(sat_lat<=0 && sat_lon>=150)
        {t1=fabs(lat)-fabs(sat_lat);
         t1=fabs(t1);
         t2=(180-sat_lon)+(180-fabs(lon));
         td=t1+t2;
         if(td<total_dif)
             {total_dif=td;
              ansr=i;
             }
        }
    }
}
/*closes lat<0 */
/*closes fabs<18*/
/*closes loop*/
return(ansr);
/*end get_sat*/

```

/\* The Adj\_matrix function is used to determine the adjancecy matrix for the satellite system. It constructs an n x n matrix of zeroes and ones. Elements of this matrix are either a zero or a one. A one in position ij indicates that there is an edge, or cross-link, between satellites i and j When called the function requires two intergers- the number of orbital planes and the number of satellites per plane. The function will ask the satellite number within a plane that is not able to maintain cross links to the left and right. For Iridium there will be 3 satellites in each plane that are not able to maintain cross-links. This adjancy matrix will hold as long as the geometry of the situation is stable, that as long as the list of satellites maintianing cross link and the list not maintaing cross links is constant. For Iridium, the geometry remain constant for the first 3 minutes and 30 seconds of a satellite pass over a ground station. The second geometry remains constant for the remainder of the pass of a single satellite over a ground station \*/

```

adj_matrix Adj_matrix(int p, int sats)
{ adj_matrix X;
  int i,j,n,x,y,z;
  n=(p*sats)-1;
  cout<<"Enter the first satellite number that has lost L/R link"<<endl;
  cin>>x;

```



```

cout<<"Enter the second satellite number that has lost L/R link"<<endl;
cin>>y;
cout<<"Enter the final satellite number that has lost L/R link"<<endl;
cin>>z;
/* These are used to make sure that satellits with no L/R link are not
credited with an edge in the adjancey matrix. 1 is subtracted from each
because C++ arrays start at 0,0 ie if the 1 satellites have no cross link
than that corresponds to the 0 satellites in the matrix*/
x=x-1; y=y-1; z=z-1;

/*set all values of the adjancey matrix equal to zero*/
for(i=0;i<=n;i++)
{for(j=0;j<=n;j++)
    X.A[i][j]=0;
}

/*set the values of A to one for the in-plane ie front and back cross-links*/
for(i=0;i<=n;i++)
{for(j=0;j<=n;j++)    /* % is the mod function*/
    {if(i==j && i%11>0 && (i+1)%11>0)
        {X.A[i][j-1]=1;
        X.A[i][j+1]=1;
        }
    if(i==j && i%11==0)
        {X.A[i][j+1]=1;
        X.A[i][j+10]=1;
        }
    if(i==j && (i+1)%11==0)
        {X.A[i][j-1]=1;
        X.A[i][j-10]=1;
        }
    /*set the values for the left and right cross links*/
    if(i==j && i>10 && i<55 && i!=x+11 && i!=x+22 && i!=x+33 &&
i!=x+44
        && i!=y+11 && i!=y+22 && i!=y+33 && i!=y+44 &&
        i!=z+11 && i!=z+22 && i!=z+33 && i!=z+44)
        {X.A[i][i-11]=1;
        X.A[i][i+11]=1;
        }
    if(i==j && i<=10 && i!=x && i!=y && i!=z)
        {X.A[i][i+11]=1;
        X.A[i][i+55]=1;
        }
    if(i==j && i>=55 && i!=x+55 && i!=y+55 && i!=z+55)

```

```

        {X.A[i][i-11]=1;
          X.A[i][i-55]=1;
        }
      }
    }
    return(X);
}/*end Adj_matrix*/

```

/\* The Adj\_matrix\_mid function is used to determine the adjacency matrix for the satellite system when the system is in a transitional geometry. It constructs an n x n matrix of zeroes and ones. Elements of this matrix are either a zero or a one. A one in position ij indicates that there is an edge, or cross-link, between satellites i and j. When called the function requires two integers- the number of orbital planes and the number of satellites per plane. The function will ask the satellite number within a plane that is not able to maintain cross links to the left and right. For Iridium there will be 4 satellites in each plane that are not able to maintain cross-links during transitional geometry. Transitional geometry is considered to occur when a satellite A is sending information to a satellite b and the geometry changes before satellite A can reach B, that is epsilon passes while that message is on an intermediate satellite.

```

*/
adj_matrix Adj_matrix_mid(int p, int sats)
{ adj_matrix X;
  int i,j,n,x,y,z,z2;
  n=(p*sats)-1;
  cout<<"Enter the satellites w/out L/R link for transitional geometry"<<endl;
  cout<<"Enter the first satellite number that has lost L/R link"<<endl;
  cin>>x;
  cout<<"Enter the second satellite number that has lost L/R link"<<endl;
  cin>>y;
  cout<<"Enter the third satellite number that has lost L/R link"<<endl;
  cin>>z;
  cout<<"Enter the final satellite number that has lost L/R link"<<endl;
  cin>>z2;
  /* These are used to make sure that satellites with no L/R link are not
  credited with an edge in the adjacency matrix. 1 is subtracted from each
  because C++ arrays start at 0,0 ie if the 1 satellites have no cross link
  than that corresponds to the 0 satellites in the matrix*/
  x=x-1; y=y-1; z=z-1; z2=z2-1;

  /*set all values of the adjacency matrix equal to zero*/
  for(i=0;i<=n;i++)
    {for(j=0;j<=n;j++)

```

```

        X.A[i][j]=0;
    }

/*set the values of A to one for the in-plane ie front and back cross-links*/
for(i=0;i<=n;i++)
    { for(j=0;j<=n;j++)        /* % is the mod function*/
        { if(i==j && i%11>0 && (i+1)%11>0)
            { X.A[i][j-1]=1;
              X.A[i][j+1]=1;
            }
          if(i==j && i%11==0)
            { X.A[i][j+1]=1;
              X.A[i][j+10]=1;
            }
          if(i==j && (i+1)%11==0)
            { X.A[i][j-1]=1;
              X.A[i][j-10]=1;
            }
        }
/*set the values for the left and right cross links*/
if(i==j && i>10 && i<55 && i!=x+11 && i!=x+22 && i!=x+33 &&
i!=x+44
        && i!=y+11 && i!=y+22 && i!=y+33 && i!=y+44 &&
        i!=z+11 && i!=z+22 && i!=z+33 && i!=z+44 &&
        i!=z2+11 && i!=z2+22 && i!=z2+33 && i!=z2+44)
    { X.A[i][i-11]=1;
      X.A[i][i+11]=1;
    }
    if(i==j && i<=10 && i!=x && i!=y && i!=z)
    { X.A[i][i+11]=1;
      X.A[i][i+55]=1;
    }
    if(i==j && i>=55 && i!=x+55 && i!=y+55 && i!=z+55)
    { X.A[i][i-11]=1;
      X.A[i][i-55]=1;
    }
    }
    }
return(X);
}/*end Adj_matrix_mid*/

FILE* fopener(void)
{
    FILE* fp;
    char filename[40], mode[4];
    /* Input the filename and mode */

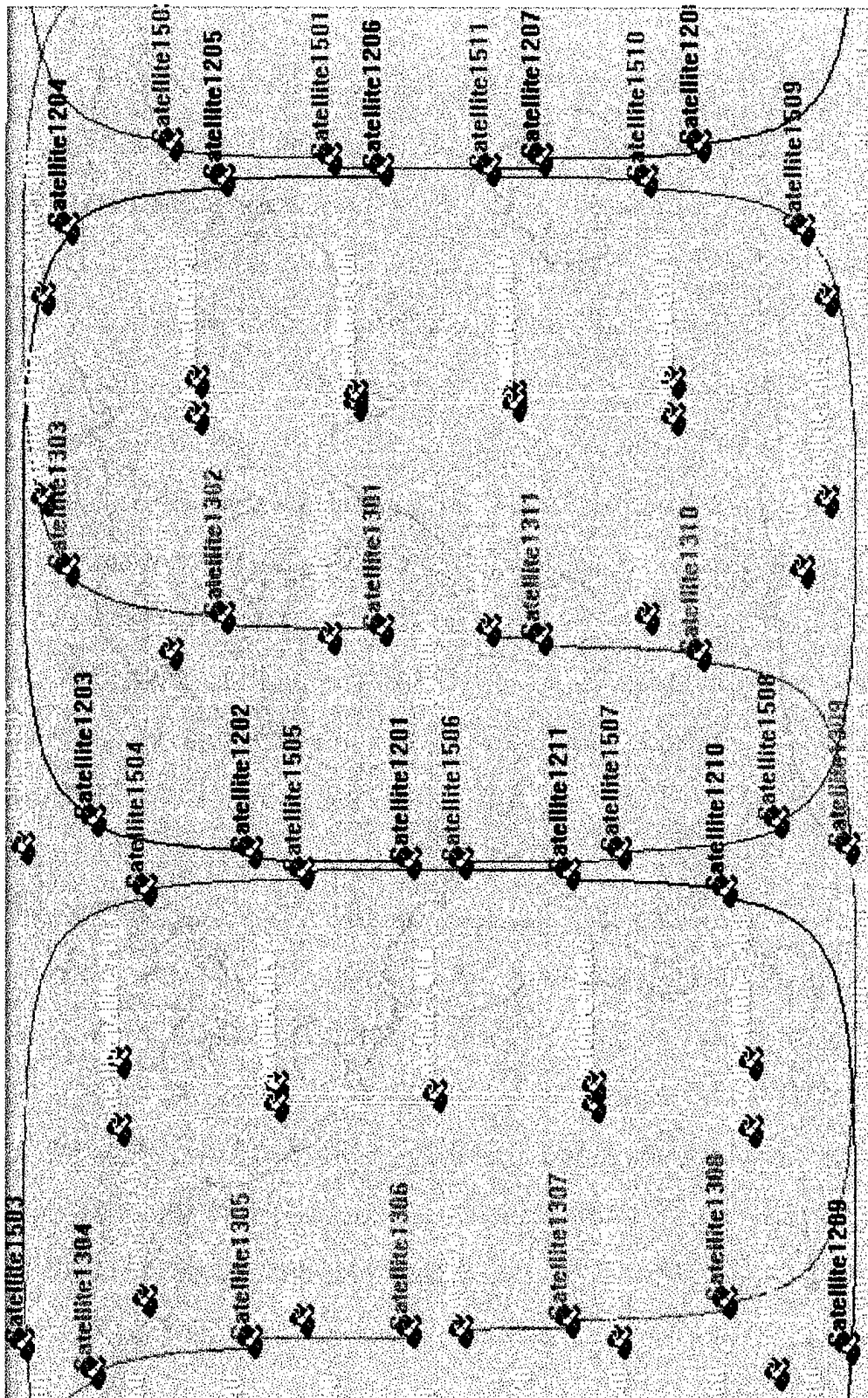
```

```
printf("\n Enter a filename you wish to open:");
gets(filename);
printf("\n Enter the mode: r to read, w to write:");
gets(mode);

/* Try to open the file */
if ((fp=fopen(filename,mode)) != NULL)
    {printf("\n File %s in mode %s opened", filename, mode);
      return (fp);}
else
    {printf("\n File %s not able to be opened", filename);
      return(NULL);}
}
```

## Appendix 4

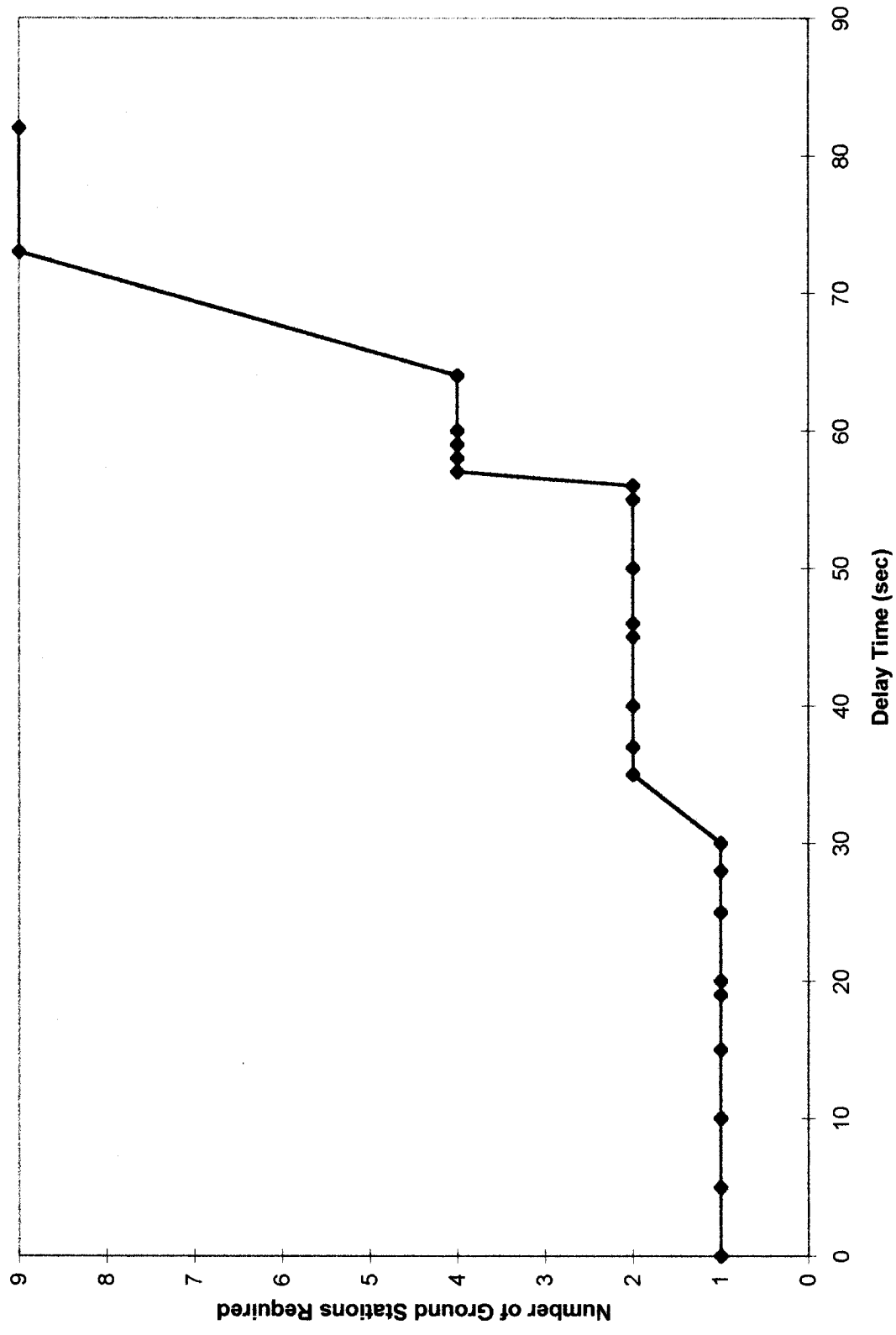
Reproduced From  
Best Available Copy



## Appendix 5

Chart1

Transmission Queue Delay vs. Required Ground Stations





#### Ground Station Results for Optimization

For p=0, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=1, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=5, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=10, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=15, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=19, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=20, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=25, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=28, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=30, the number of ground stations was 1

Lat=65.000000      Lon=180.000000

For p=35, the number of ground stations was 2

Lat=65.000000      Lon=180.000000

Lat=65.000000      Lon=160.000000

For p=37, the number of ground stations was 2

Lat=65.000000      Lon=180.000000

Lat=65.000000      Lon=160.000000

For p=40, the number of ground stations was 2

Lat=65.000000      Lon=180.000000

Lat=65.000000      Lon=160.000000

For p=45, the number of ground stations was 2

|               |                 |
|---------------|-----------------|
| Lat=65.000000 | Lon=180.000000  |
| Lat=35.000000 | Lon=-135.000000 |

For p=46, the number of ground stations was 2

|               |                 |
|---------------|-----------------|
| Lat=65.000000 | Lon=180.000000  |
| Lat=35.000000 | Lon=-135.000000 |

For p=50, the number of ground stations was 2

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=-35.000000 | Lon=180.000000 |

For p=55, the number of ground stations was 2

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=-35.000000 | Lon=180.000000 |

For p=56, the number of ground stations was 2

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=-35.000000 | Lon=180.000000 |

For p=57, the number of ground stations was 4

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=-5.000000  | Lon=180.000000 |
| Lat=-20.000000 | Lon=180.000000 |
| Lat=65.000000  | Lon=75.000000  |

For p=58, the number of ground stations was 4

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=-5.000000  | Lon=180.000000 |
| Lat=-20.000000 | Lon=180.000000 |
| Lat=65.000000  | Lon=75.000000  |

For p=59, the number of ground stations was 4

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=-5.000000  | Lon=180.000000 |
| Lat=-20.000000 | Lon=180.000000 |
| Lat=65.000000  | Lon=75.000000  |

For p=60, the number of ground stations was 4

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=-5.000000  | Lon=180.000000 |
| Lat=-20.000000 | Lon=180.000000 |
| Lat=65.000000  | Lon=75.000000  |

For p=64, the number of ground stations was 4

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=-5.000000  | Lon=180.000000 |
| Lat=-20.000000 | Lon=180.000000 |
| Lat=65.000000  | Lon=75.000000  |

For p=73, the number of ground stations was 9

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=35.000000  | Lon=160.000000 |
| Lat=0.000000   | Lon=105.000000 |
| Lat=-45.000000 | Lon=-50.000000 |
| Lat=-35.000000 | Lon=-10.000000 |
| Lat=65.000000  | Lon=60.000000  |
| Lat=-20.000000 | Lon=-75.000000 |
| Lat=65.000000  | Lon=130.000000 |
| Lat=-5.000000  | Lon=180.000000 |

For p=82, the number of ground stations was 9

|                |                |
|----------------|----------------|
| Lat=65.000000  | Lon=180.000000 |
| Lat=35.000000  | Lon=160.000000 |
| Lat=0.000000   | Lon=105.000000 |
| Lat=-45.000000 | Lon=-50.000000 |
| Lat=-35.000000 | Lon=-10.000000 |
| Lat=65.000000  | Lon=60.000000  |
| Lat=-20.000000 | Lon=-75.000000 |
| Lat=65.000000  | Lon=130.000000 |
| Lat=-5.000000  | Lon=180.000000 |